GUIDE
to the
PLANETS

PATRICK
MOORE

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by PATRICK MOORE
F.R.A.S.

Author of "GUIDE to the MOON"

Eyre &
Spottiswoode

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ALL the strange diversity of the planets comes alive in this book. Written with rigorous scientific accuracy, but also with uncanny vividness, it explores the Solar System, recounting its history and the history of man's discovery of it, and describing in turn each of the planets and their satellites.

Here, for instance, is the innermost planet, Mercury, containing on its small globe both the hottest and the coldest places in the Solar System. Here is Venus, shrouded perpetually in heavy clouds, but one of the only two planets that could support a form of life. (The other is, of course, Mars, where plant life at any rate is almost certain.) And here is that strange member of the asteroid family, a cigar-shaped lump of rock about the size of the Isle of Wight, endlessly floating through space.

What will it feel like to journey to the planets? Surprisingly, we already know in considerable detail. *Guide to the Planets* recounts several such journeys, beginning with the take-off from an artificial satellite, built to circle the earth a thousand miles up, and ending in the alien landscape of another world.

Behind all this is the intricate mass of astronomical observations on which the whole picture is built up. Patrick Moore describes the instruments and techniques by which we have come to know so much about bodies some of which are so small and distant as to be wholly invisible even through a medium-sized telescope.

The would-be astronomer, equipped with a small or moderate telescope, will find the appendices of particular interest, as they contain full instructions on how to set about planetary observation.

He will be glad, too, to find that Patrick Moore lays stress on the debt that our present knowledge owes to the work of amateurs and on the amount of useful research they can still do, even in this age of giant and complex equipment.

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PLATE I. Two views of Mars (*above:* 1935, May 20, ×326, L. F. Ball; *below:* 1935, Apr. 14, ×350, L. F. Ball)

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To Dr. H. P. Wilkins

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Foreword

This book, a companion volume to my *Guide to the Moon,* does not set out to be a text-book in the ordinary sense of the word. As the title implies, it is a guide for those engaged upon actual telescopic observation of the planets and for those who wish to learn something about our neighbour worlds. Though much of what I have written may be out of date in a few years, I have attempted to summarize present information in language that can be understood by anyone; and only in Chapter 9 have I allowed myself to speculate.

Once again I have received invaluable help from many people. In particular I must thank E. A. Whitaker of Greenwich Observatory, Dr. H. P. Wilkins, A. L. Helm, John Smith and R. Warren Fisher, all of whom read through the manuscript in its rough form and made many helpful suggestions, while Arthur C. Clarke, chairman of the British Interplanetary Society, read through the chapter dealing with space-flight.

Of my American friends, I must make special mention of David P. Barcroft, who has gone to endless trouble to obtain information which would not otherwise have been accessible to me, and has, throughout, given me help and encouragement in all possible ways.

The book has been enriched by the inclusion of some of the beautiful drawings of L. F. Ball, to whom I am deeply grateful. Others who have generously allowed me to reproduce their drawings are: R. Barker (map of Mars), R. M. Baum (Venus), F. C. Butler (Venus), R. L. T. Clarkson (Venus), T. L. Cragg (Neptune), H. McEwen (Mercury), E. J. Reese (map of Ganymede), Günter D. Roth (Jupiter), Dr. Werner Sandner (map of Mercury), and Tsuneo Saheki (Mars). Dr. Wilkins and A. L. Helm have also prepared drawings for me, in addition to all their other help. I must thank the Observatories of Mount Palomar and Mount Wilson for permission to reproduce drawings and photographs, and also the Astronomer Royal, who has allowed me to use some photographs taken by Mr. Whitaker at Greenwich. MM. Gau-

thier-Villars, of Paris, have been kind enough to let me reproduce E. M. Antoniadi's famous map of Mercury.

Dr. W. H. Steavenson, who was largely responsible for my early interest in astronomy, has given me invaluable advice upon certain debatable points; and I am also grateful to W. A. Trotter for some helpful suggestions concerning the original plan of the book. Finally, I must not omit to record my appreciation of the unfailing help and encouragement afforded me by the publishers.

PATRICK MOORE.

East Grinstead.
July, 1954.

GUIDE TO THE PLANETS

CHAPTER I

The 'Wandering Stars'

Astronomy is the oldest of all the sciences. Many thousands of years ago, when mastodons and mammoths still prowled the forests, and the civilizations of China and Egypt still lay in the far future, men must have looked up at the heavens and wondered at what they saw there. The Sun, providing life-giving warmth, and the Moon, softening the darkness of night, came to be regarded as gods; but what of the stars – tiny, twinkling points of light, cold and remote, fading away in the light of dawn not to be seen again until after the Sun had set? The earliest men, struggling to understand things beyond their understanding, must have puzzled greatly.

Gradually, knowledge grew. It was still supposed that the Earth was the centre of the universe, and indeed this idea persisted until less than five hundred years ago; but it was realized that while the Sun and Moon wandered about the sky, within certain limits, the stars remained fixed in the celestial vault, only sharing in the general daily rotation. Picture a balloon with spots of paint upon it. If the balloon is twisted, the spots of paint will move round the axis of rotation; but they will move in a mass, and not relative to each other. Now picture a fly crawling across the balloon as it spins. The fly will not only share in the general movement of the paint-spots, but it will move in relation to the paint-spots, just as the Sun and Moon do in relation to the stars.

Later, though still so long ago that we have no records of the actual period, it was seen that the Sun and Moon were not the only 'flies on the balloon'. There were other bodies, too, which seemed to shift and alter in position from night to night, even though there was little else to distinguish them from ordinary stars. These were named 'wandering stars', or 'planets'; and at the start of recorded history, five were known. The Greeks and Romans gave them appropriate names. The little planet that kept close to the Sun, quick-moving and difficult to see, was called Mercury, after the fleet-footed messenger of the gods. The beauti-

ful 'evening star' was named in honour of Venus, the goddess of love; Mars, the god of war, gave his name to the red planet that glows in the heavens like a drop of blood; Jupiter, the king of the gods, was associated with the largest and most important planet; and finally, the slow-moving planet that shone with a dull yellowish light was named after Saturn, the god of time. These five, together with the Sun and Moon, made up seven 'wanderers'; and as seven was the magical number of the ancients, the system was assumed to be complete.

The first real scientific records, those of the Chinese, go back to the dawn of history, and there is excellent evidence that an eclipse of the Moon was intelligently observed as long ago as B.C. 1136 – over a hundred years before the Trojan War. But the Chinese, and also the Egyptians, were content to observe without asking 'why' or 'how', and it was left to the Greeks to make the first speculations as to the nature and character of the heavenly bodies.

The story of Greek astronomy begins with the birth of Thales of Miletus in B.C. 624, and virtually ends with the death of Ptolemy of Alexandria in A.D. 180, so that it extends over a period of some eight hundred years – quite long enough to effect a complete revolution in human outlook. One of the greatest of the Greek scientists, Aristarchus of Samos, who flourished about B.C. 280, is particularly noteworthy because he was almost the first to maintain that the Earth revolves round the Sun, not vice versa; and though his ideas were violently condemned at the time (he was centuries in advance of his age), he had planted a seed which came to full flower nearly two thousand years later, when first Copernicus and then Kepler showed conclusively that the Earth is merely a junior member of the Sun's family of planets.

It is a blow to our vanity to learn that the Earth is no more important cosmically than is a single sand-grain in the Sahara, but we have to accept the fact. Astronomical distances are, indeed, rather too much for us to appreciate; though we can talk in terms of millions of miles, we cannot really understand what is meant. Let us, therefore, represent the Solar System upon a scale which is more within the range of our ordinary experience; and it will be convenient to make the Sun a globe 600 feet in

diameter, placed just outside the Houses of Parliament at Westminster. The planets can now be filled in:

Mercury, 2 feet in diameter, 4⅔ miles away (in Hampstead Heath).

Venus: 5¼ feet in diameter, 9 miles away (in Mill Hill).

The Earth: 5½ feet in diameter, 12¼ miles away (in Barnet).

Mars: 3 feet in diameter, 18½ miles away (in St. Albans).

The 'Asteroids' or Minor Planets: tiny globes ranging from under a millimetre to three inches in diameter, at an average distance of some 30 miles.

Jupiter: 60 feet in diameter, 64 miles away (in Northampton).

Saturn: 51 feet in diameter, 117 miles away (in Lincoln).

Uranus: 22 feet in diameter, 236 miles away (in Sunderland).

Neptune: 19½ feet in diameter, 370 miles away (in Montrose).

Pluto: 2½ feet in diameter, 485 miles away (in Wick).

If we exclude Pluto, which presents some special problems, it will be seen that the planets fall into two distinct groups – one made up of small planets (Mercury to Mars) and the other of giants, with the asteroids in between.

We must not forget the moons or 'satellites' which revolve round some of the planets. The Earth has one (the Moon), Mars two, Jupiter twelve, Saturn nine, Uranus five and Neptune two, while Mercury, Venus and Pluto do not seem to be favoured with any. These satellites are of various sizes. Some are planet-sized worlds; indeed, Titan, the largest of Saturn's attendants, is appreciably larger than Mercury. Others, such as the two tiny moons of Mars, are truly Lilliputian.

Unfortunately this scale, which is quite suitable for the Solar System, is of no use at all for the stars. Light, hurrying along at 186,000 miles a second, takes 5½ hours to travel from the Sun to Pluto; but the light from the nearest star takes over four years to reach us. (It must, of course, be borne in mind that the stars are self-luminous, whereas the planets shine only by reflected sunlight.) If we reduce our scale still more, so that the Sun shrinks to only one foot in diameter and the Earth becomes a small bead 36 yards away, the nearest star will lie at a distance of 5,500 miles,

somewhere in Russia. Even the conventional mile becomes too small for convenient use, and we generally replace it by the

FIG. 1. The Solar System to scale

'light-year', which is the distance travelled by a ray of light in one year – just under six million million miles.

The fact that the stars are so inconceivably remote explains why they appear to remain stationary in relation to each other.

They are not really fixed; on the contrary, they are moving at speeds many times in excess of that of our fastest jet-aircraft – but it takes years for their motions to become appreciable. The planets, so much closer, show their movements more readily. There is a perfect analogy with a leisurely bee a few yards above the ground, and a high-flying jet-aircraft several miles up. The bee's motion will be far more noticeable than the jet's, even though there is as yet no record of any bee having undergone the experience of breaking through the sound barrier!

The Sun is the unquestioned ruler of the Solar System. It provides the planets with warmth and light, and its powerful gravitational pull controls their movements. Without the Sun, the human race could not survive for an instant. Yet the planets are perhaps more interesting to us today. They are worlds not so very unlike our own, and there seems a definite possibility of our being able to reach some of them in the not-so-distant future.

Space-travel has occupied men's minds for thousands of years, and as long ago as A.D. 160 a Greek writer, Lucian, wrote a story about a voyage to the Moon which may be considered the true ancestor of 'science fiction'. At that time, and so long as it was impossible to rise more than a few feet above the ground, interplanetary flight was bound to remain a fantastic dream; even the balloon and the aeroplane were of no help, as both depend upon air for their lift, and there is no air out in space. However, the rocket is not similarly handicapped. It is at its best in total vacuum, and the great development of rocket science during the last twenty years has made space-travel more than a mere possibility.

We must revise our ideas about the planets. Far from being remote, inaccessible worlds, they have become possible colonies. Our own Earth has been stripped of its wonders; from the heights of Everest to the depths of the Pacific there is little new to find, but men of the twenty-first century may find their wonders in other worlds. Our knowledge is growing rapidly, and some of those who read this book may well live long enough to witness the first of all voyages into space. There is nothing fantastic in the suggestion that our grandchildren and great-grandchildren may wander among the rocks of the Moon or explore the dusty wastes of Mars.

CHAPTER 2

The Birth of the Planets

The problem of how the Earth came into being is a most fascinating one, and has always intrigued the minds of men. Ancient mythology abounds with stories about the Creation; for instance, the Iroquois Indians of North America believed that "a heavenly woman was tossed out of Heaven, and fell upon a turtle, which grew into the Earth". Unlikely as this idea seems, it is really no stranger than some of the theories which have been put forward in much more modern times.

So long as it was believed that the Earth held a special position in the universe, no real progress could be made. The problem of the birth of our own world is bound up with that of the formation of all the other planets; once we know definitely how the Earth was created, we shall be well on the way to solving most of the mysteries of evolution.

Unfortunately, we must admit that our ideas are still rather vague. No theory yet put forward can be considered really satisfactory; all we can do at the moment is to collect what evidence we have, and put the best possible interpretation on it.

Perhaps the first thing to do is to work out just how old the Earth is, and here we are on comparatively safe ground. It seems certain that the age of the Earth is between two and three thousand million years. Of course, such an enormous lapse of time is quite beyond our understanding. Recorded history carries us back some way into the past, and archæological research increases the time-span still more; but even the study of fossils, which takes us back millions of years, can only give us information about the more recent events in the Earth's life-story. The age of our planet has been estimated mainly from investigations into the behaviour of uranium, the heaviest of all natural elements and the substance which has recently achieved notoriety by its usefulness in the manufacture of atomic bombs.

Uranium is slightly 'radioactive'; it decays gradually into other elements, finishing its career as lead. The lead formed in this way

can be distinguished from ordinary lead, and so the quantity of uranium-lead associated with the remaining uranium tells us how long ago the decaying process started. Fortunately, the rate of decay seems to be completely unaffected by conditions of temperature or pressure, and the process is very slow indeed. The uranium in the oldest rocks turns out to be some two thousand million years old, which gives a lower limit to the Earth's existence as a solid body; the history of our planet as a separate globe is unlikely to go back much more than a thousand million years further. Assuming that the Earth was formed in the same manner and at about the same time as the other planets, which seems more than probable, we have thus found a key to the age of the Solar System. We have made a great deal of progress since the year 1654, when Archbishop Ussher of Armagh stated categorically that the world had been created at nine o'clock in the morning of October 26, B.C. 4004[1].

It is safe to assume that the planets were formed either from the Sun itself, or from a companion star associated with the Sun, or from a cloud of diffuse matter surrounding the Sun. It only remains to work out the actual process of formation, but here our difficulties begin.

In 1796, Laplace, one of the greatest of French astronomers, published his famous 'Nebular Hypothesis', which was generally accepted for many years. Earlier theories advanced by Swedenborg, Wright and Kant were somewhat similar, but Laplace seems to have been the first to tackle the problem in a really scientific way. He started with the idea of a vast gas-cloud, disk-shaped and in slow rotation, and worked out an evolutionary sequence ending in a system composed of a central Sun, planets, and satellites.

Laplace supposed that as the gas-cloud cooled down, radiating its heat away into space, it shrank; as it shrank, its rate of spin increased, until the centrifugal force at its edge became equal to the gravitational pull there. At this stage a ring of matter broke away from the main mass, and gradually this ring condensed into a planet. As the shrinkage of the main mass continued, a

[1] This value was adopted by the Church for many years. It is not, however, clear whether the Archbishop had made due allowance for the various revisions of the Calendar!

second broken-off ring gave rise to another planet; and the process was repeated a number of times, so that the final result was a central Sun surrounded by a retinue of circling worlds. This would mean that the outermost planets were the oldest, and that Mercury, the closest planet to the Sun, was the youngest member of the solar family.

At first sight the 'Nebular Hypothesis' looks very plausible. Unfortunately, however, it has not stood up to the rigorous tests of mathematical analysis, and there are a number of fatal objections to it. For instance, it has been shown that the material shed during the shrinking of the gas-cloud would not form separate rings – and in any case, such rings could never condense into planets. This in itself is enough to destroy the whole theory, but there is an equally serious objection which is worthy of notice.

If we consider one body revolving round another, and multiply together its mass, its distance and its velocity, we shall obtain what is known as its 'angular momentum'. It is a fundamental principle that angular momentum can be transferred, but never destroyed; so that on Laplace's theory all the angular momentum now possessed by the Sun and planets must originally have been concentrated in the gas-cloud. At present, almost all the angular momentum of the Solar System is concentrated in the four giant planets Jupiter, Saturn, Uranus and Neptune – whereas if Laplace's ideas were correct, we should expect to find most of the angular momentum concentrated in the Sun itself. There is no evading this difficulty, and we must reluctantly conclude that the whole theory is absolutely unworkable.

No plausible alternative ideas were put forward for over a century, but in 1900 two American scientists, Chamberlin and Moulton, formulated the first of the 'tidal' theories, involving not only the Sun itself but also a second star.

Space is very empty. It is true that the Sun, which is a perfectly ordinary star, is a vast body with a diameter of over three-quarters of a million miles; but if we represent it by a tennis ball, the nearest of its neighbours will be over a thousand miles away. Two mosquitoes flying about inside the Royal Festival Hall would be far more likely to collide than any two stars. Nevertheless, it is within the bounds of possibility that some time in its history the Sun did pass dangerously close to another star;

and such an encounter would have far-reaching effects, since the gravitational strain set up between the two bodies would be tremendous.

Chamberlin and Moulton supposed that such an encounter did occur. As the second star approached the Sun, massive tides were raised, both upon the star and upon the Sun itself, until at last a large quantity of matter was torn away from the Sun and sent spiralling round it. We can only begin to imagine the scene when the two stars were only a few million miles apart – great streamers of gas and torn-off matter circling the wounded Sun, while immense tides, augmented by Titanic eruptions within the Sun itself, reached incredible violence, lessening at last as the intruder moved away.

Having done its work, the wandering star retreated into the distance, leaving the Sun surrounded by a cloud of débris. Slowly this débris cooled down and solidified into small particles or 'planetesimals'; now and then aggregations of these planetesimals formed, and in a few cases the aggregations were large enough to collect other planetesimals by gravitational attraction. Gradually, almost all the planetesimals were collected into a few large lumps, the final result being a system of planets.

Once an aggregation reached a diameter of perhaps a hundred miles, its gravitational pull would become so strong that it would grow comparatively quickly into a body of planetary dimensions; but under the conditions assumed by Chamberlin and Moulton, there seems grave doubt as to whether the initial aggregations could ever reach sufficient size for the collecting process to become possible.

Sir James Jeans, well remembered for his popular books and broadcasts as well as for his more serious works, recognized this difficulty, and put forward a modified tidal theory according to which the planets condensed out of a long, cigar-shaped filament drawn out of the Sun by the pull of the passing star. A particularly attractive feature of this idea is that it would account for the largest planets (Jupiter and Saturn) being found in the middle of the 'cigar', with the smaller planets at the tapering ends. (Fig. 2). An analogous process would account for the formation of planetary satellites, the Sun now in the disturbing rôle originally played by the passing star.

Various mathematical difficulties in Jeans' theory led Sir Harold Jeffreys to suggest that the passing star actually struck the Sun a glancing blow. This was not a new idea, as it had been previously suggested (though in a somewhat garbled form) by A. W. Bickerton, but the actual process of planet formation remained much the same as Jeans had supposed. Unfortunately, even this modification did not remove all the objections. The distribution of angular momentum remained as big a problem as ever, and incidentally the material which makes up the Earth and its fellow-planets is not what would be expected if it had been torn directly off the Sun; but there is another difficulty which seems to deal a death-blow to all tidal theories. This has to do with the composition of the Sun itself.

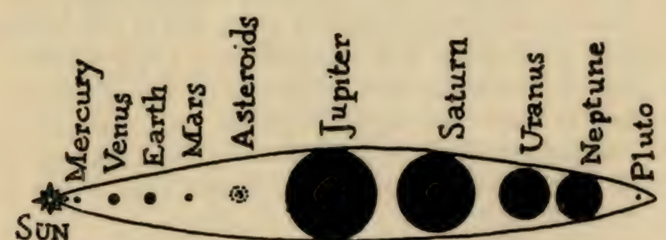


FIG. 2. Jeans' tidal theory

The Sun is intensely hot. Even its surface has a temperature of almost 6,000° C., and lower down the heat increases until at the centre it has reached about twenty million degrees C. – beside which even the most violent atomic bomb yet made is about as warm as a firefly compared to a powerful electric stove. The hot gases inside the Sun are only prevented from expanding and escaping by the crushing pressure of the overlying layers. What would happen if a vast quantity of material were suddenly torn away by tidal action or by collision with another star? The pressure would be released, and the gases would expand with such violence that no planet-building process would be even remotely possible.

It must be remembered that the process would not be a lengthy one. On Jeffreys' theory, the grazing collision would be over in a few hours, so that the disturbances in the Sun and in the passing star would be upon a scale that we cannot even begin to picture. No solution to this difficulty has yet been found, and it is now generally agreed that all tidal and collision theories must be classed with Laplace's 'Nebular Hypothesis' as "ingenious, but not correct".

Sir James Jeans calculated that on an average, any particular star would pass close by another only once in every five hundred thousand billion years. No star is anything like as old as this, and so the vast majority of stars will not have undergone the experience; but it would be wrong to suppose that each star is a solitary wanderer in space.

Nearly everyone is familiar with the constellation known as the Great Bear. The second star in the tail is named Mizar, easily identifiable as a much fainter star, Alcor, lies close beside it. When a telescope is used, Mizar itself appears as two stars, about equally bright and so close together that to the unaided eye they appear as one. This is no mere perspective effect; the two stars really are associated, and revolve round their common centre of gravity, much as the two bells of a dumb-bell move when twisted by the joining arm. They form what is known as a 'binary' or double star system.[1]

Binary stars are very common, and attempts have been made to account for the Sun's system of planets by supposing that the Sun itself was formerly one component of a binary pair. For instance, H. N. Russell suggested that it was the companion star which was struck by the intruder, giving rise to enough débris to account for the planets; Dr. R. A. Lyttleton considered that the near approach of the intruding star might be enough to wrench the binary companion away from the Sun's sphere of influence, planet-forming matter being scattered in the process. Perhaps the most interesting variation of the binary theory, however, is due to Hoyle; this dispenses with an intruding star altogether.

According to Hoyle, the Sun was originally one member of a binary system, the companion being about as far away from it as Jupiter is at present. The Sun was a perfectly ordinary star,

[1] The system of Mizar is actually more complicated than this; but there are many binary systems which consist simply of two stars almost identical in size and mass.

but its companion was not; some three thousand million years ago it exploded with a catastrophic blaze of light and heat that equalled the combined radiance of all the other stars in the galaxy put together. We know that such stellar outbursts do occur now and then. They are known as 'supernovæ', and can be seen across space from distances of millions of light-years.

In a supernova explosion, most of the star's material is hurled out into space at a speed of millions of miles an hour; the whole outburst lasts only a few days, so that the energy generated is tremendous. Hoyle has calculated that one of the effects of the explosion would be to give what was left of the star a recoil sufficient to break its gravitational connection with the Sun. During the last stages of its outburst, probably as it started its never-ending journey into the depths of space, the companion ejected a cloud of gas that the Sun managed to retain. The planets then condensed out of this gas in much the way that Chamberlin and Moulton had supposed in their original 'planetesimal' theory – only this time the conditions would be much more favourable for the formation of large lumps of matter.

If Hoyle's theory is right, the original companion star may still be visible to us, even though we cannot recognize it. A supernova does not destroy itself completely. From being a massive star of enormous dimensions, it collapses into a special type of star known as a white dwarf, of small size (comparable to that of the Earth) and a density so great that a thimbleful of white dwarf material would weigh hundreds of tons. There are plenty of white dwarfs comparatively close to us in space, and one of these may well be the Sun's erstwhile attendant.

However, we may be quite wrong in supposing that the Solar System had a catastrophic origin at all. An entirely different theory has recently been put forward by the German investigator C. von Weizsäcker, and has gained a great deal of support.

All space is filled with gas, but the density of this gas is unbelievably small – many times less than the most perfect vacuum we can produce in the laboratory. However, denser parts of the gas-cloud exist, and according to von Weizsäcker the Sun ploughed through a comparatively dense region, collecting an extensive gaseous envelope as it went. Upon emerging from the cloud, the Sun was thus left with a tenuous shell of gas extending farther than the present orbit of Pluto, the outermost planet. We can at once see a certain similarity to the old theories of Kant and Laplace, though the process as suggested by von Weizsäcker is actually very different.

Gradually, collisions and friction between the particles of the gas-cloud resulted in the formation of a circular, disk-shaped shell. As time passed, gravitational effects created aggregations of matter; when these became massive enough, they drew in more matter, so that planets were built up. Once again we return to the 'planetesimals' of Chamberlin and Moulton, but this time we can dispense with the intruding star of Jeans and Jeffreys, the cosmic disaster of Hoyle, and the impossible gaseous rings of Laplace.

There are many difficulties in the way of von Weizsäcker's theory, but it does appear highly promising. At the moment we cannot be sure that it is correct; future research should shed much more light on the whole problem.

One important aspect of von Weizsäcker's theory is sometimes overlooked. Collisions between two stars are extremely infrequent, and even supernovæ are rare; so that if we follow the ideas of Jeans or Hoyle we must regard Solar Systems as true galactic freaks. But comparatively dense interstellar clouds are common enough, and if von Weizsäcker is right it is probable that systems of planets are far from rare in the universe.

If we could look back some three to four thousand million years in time, we should find ourselves confronted with a very strange picture; a young Sun, still newly-born out of the primæval matter, unaccompanied by the familiar planets that we know, but perhaps surrounded by a vast gas-shell, or within range of the companion star which was later to sear its fellow with heat beyond all understanding. But what of the future?

We are wholly dependent upon the Sun. Our existence in the universe hangs by the slenderest thread; any marked increase or withdrawal of the solar heat would be fatal to us, just as a humming-bird dies if chilled and an ice-floe melts in the heat. We manage to survive because the conditions are just right for us, but this state of things will not continue indefinitely.

It was formerly believed that the Sun was gradually cooling down, and that all life on the Earth would eventually be frozen to death; but this view is now known to be wrong. As the Sun

ages, it is growing steadily hotter. There can be no doubt about this; in the far future, thousands of millions of years ahead yet, the oceans will boil, the atmosphere will escape into space, and all earthly things, from the descendants of men (if any survive) down to the lowliest plants, will perish. The two inner planets, Mercury and Venus, will be destroyed; Earth may well share their fate; Mars may escape, but even Jupiter and Saturn, now bitterly cold, will be scorched and withered. This state of affairs will not last for long upon the cosmical scale, for the Sun's blaze will be its last defiant gesture of departing glory. In only a few thousands of years it will collapse into a small massive body, well on the road to its own end; and at last it will reach its final condition as a cold, dark globe, lightless and heatless, while the ghosts of its remaining planets circle it in silence, bathed in eternal night. But this will not concern us – for we shall not be there to see. In the remote past, the Sun was responsible for the creation of the Earth; in the end, it will inevitably destroy its own child.

CHAPTER 3

The Movements of the Planets

The ancient peoples believed the world to be flat. It is hardly surprising that they thought so; only within the last few years has it been possible to take photographs from an altitude sufficient to show the curvature of the Earth's surface, and even today there are still people who find it difficult to believe that we live upon a globe.

Pythagoras, the great geometer who lived some 500 years before Christ, was probably the first to realize that the Earth is spherical; but to Pythagoras, as well as to most of the other Greek scientists (apart from Aristarchus, who was so much in advance of his time), the Earth was still the centre of the entire universe. It seemed unreasonable to believe that our own world was not the most important body in the cosmos, and religious leaders, in particular, were violently opposed to any other theory. Consequently, the idea of an Earth-centred system was slow to die.

The most complete system of this type was developed by Ptolemy of Alexandria, last and one of the greatest of the Greek astronomers, who believed that the Moon, Sun and planets circled round us, with the stars beyond. 'Circled' is perhaps an apt term, as the ancients believed that the circle was the perfect form and that all celestial 'orbits' (the astronomical term for 'paths') must therefore be circular. However, Ptolemy, who was a mathematician of the highest order, knew perfectly well that the observed planetary movements could not be explained by supposing each planet to revolve round the Earth in a perfect circle and at a uniform speed; and rather than adopt any alternative shape, he worked out a curious system according to which each planet moved in a small circle or 'epicycle', the centre of which itself moved in a circle around the Earth. Even this was not sufficient. More and more discrepancies came to light; more and more modifications and epicycles were introduced, until at last the whole system became hopelessly unwieldy.

Ptolemy's ideas held sway for more than a thousand years after his death, probably largely because of the unpleasant consequences of casting doubt upon them (Giordano Bruno was burned at the stake as recently as 1600, while the full might of the Roman Church crushed the spirit of the great Italian philosopher Galileo even later). In 1546, however, Copernicus, a Polish canon, published a book which caused the downfall of the Ptolemaic system. Copernicus is often over-praised; many of his ideas were very strange, and he even brought back Ptolemy's epicycles, but he did at least show that no Earth-centred theory could possibly account for the observed movements of the planets. Sixty-three years later, in 1609 (the year in which Galileo first turned his crude telescope towards the heavens), Johannes Kepler, a German mathematician, published the first of his three famous Laws upon which the whole edifice of celestial mechanics has since been built.

Although Copernicus had placed the Sun in the centre of the Solar System, he had kept to the old idea of circular orbits; and one of Kepler's most important discoveries was that the orbits of the planets are not circular, but elliptical.

The best way to draw an ellipse is to stick two pins in a board, an inch or two apart, and fasten them to the ends of a piece of cotton, leaving a certain amount of slack. Now draw the cotton tight with the point of a pencil, and trace a curve. The result will be an ellipse, the two pins marking the 'foci'. If the foci are close together, the ellipse will be almost circular; if, with the same length of cotton, the foci are wide apart, the ellipse will be long and narrow. The distance between the foci is thus a measure of the 'eccentricity' of the ellipse.

In the case of the Earth's orbit, the Sun occupies one focus; the other is empty. However, the eccentricity of the terrestrial orbit is so low that the Earth's distance from the Sun never varies by much more than a million miles from its average value of about 93 million miles.

Of the other eight major planets, only Mercury and Pluto have orbits of appreciable eccentricity. The rest move in paths which are practically circles; but although the departure from true circularity is small, it is of fundamental importance in celestial mechanics. A planet is said to be at 'perihelion'

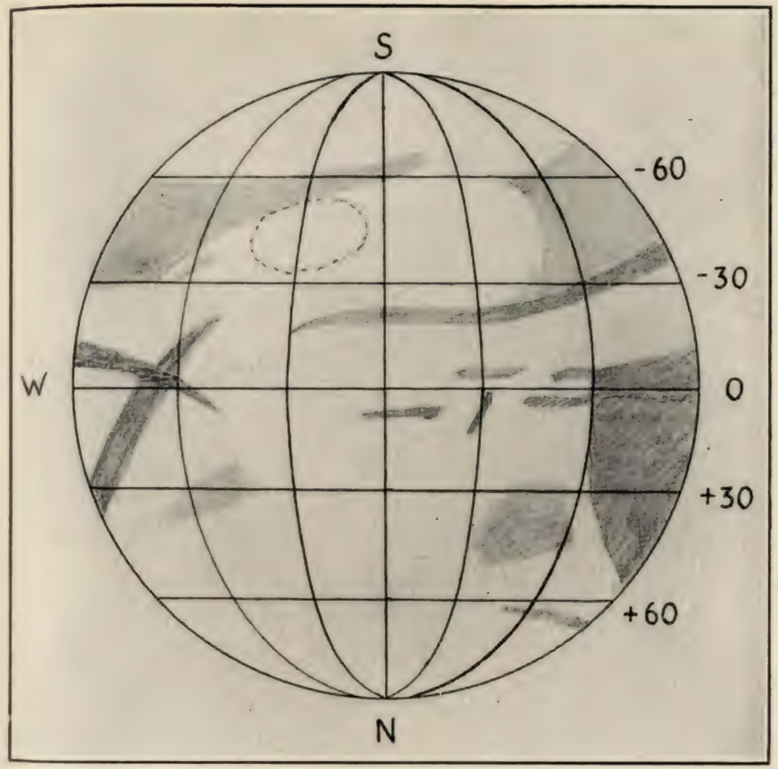
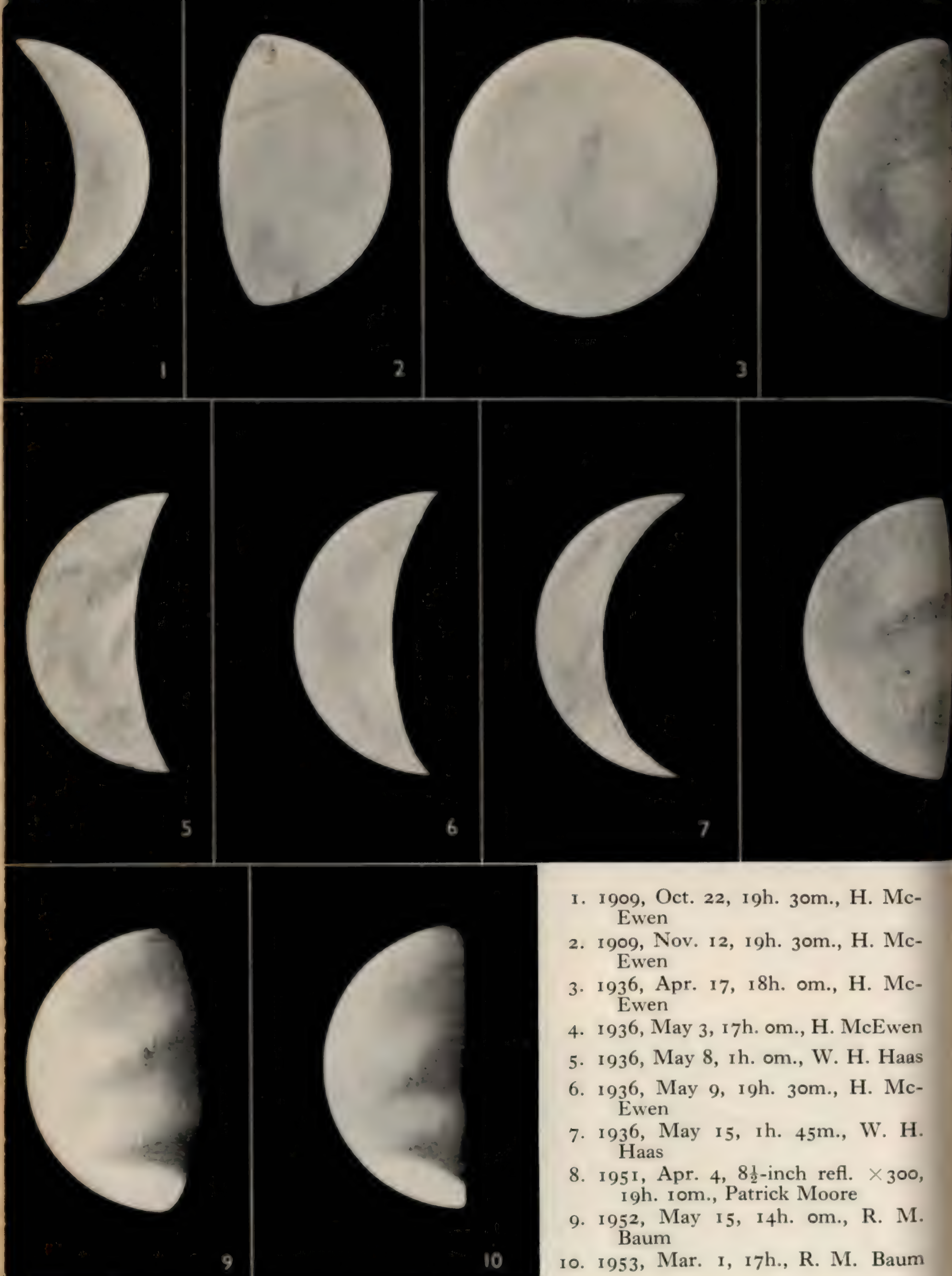


PLATE II. Sandner's map of Mercury

PLATE III. Photographs of Venus
(E. A. Whitaker, Greenwich Observatory)
(Reproduced by kind permission of the Astronomer Royal)



1. 1909, Oct. 22, 19h. 30m., H. McEwen
2. 1909, Nov. 12, 19h. 30m., H. McEwen
3. 1936, Apr. 17, 18h. 0m., H. McEwen
4. 1936, May 3, 17h. 0m., H. McEwen
5. 1936, May 8, 1h. 0m., W. H. Haas
6. 1936, May 9, 19h. 30m., H. McEwen
7. 1936, May 15, 1h. 45m., W. H. Haas
8. 1951, Apr. 4, 8½-inch refl. ×300, 19h. 10m., Patrick Moore
9. 1952, May 15, 14h. 0m., R. M. Baum
10. 1953, Mar. 1, 17h., R. M. Baum

PLATE IV. Ten drawings of Mercury

when at its closest to the Sun, and 'aphelion' when at its farthest.

In Fig. 3 the orbits of the four inner planets – Mercury, Venus, the Earth and Mars – are shown to scale, but have been drawn as circular, as their departure from the circular form would be almost inappreciable on this small scale. It would need a very large sheet of paper to show the outer planets at their correct

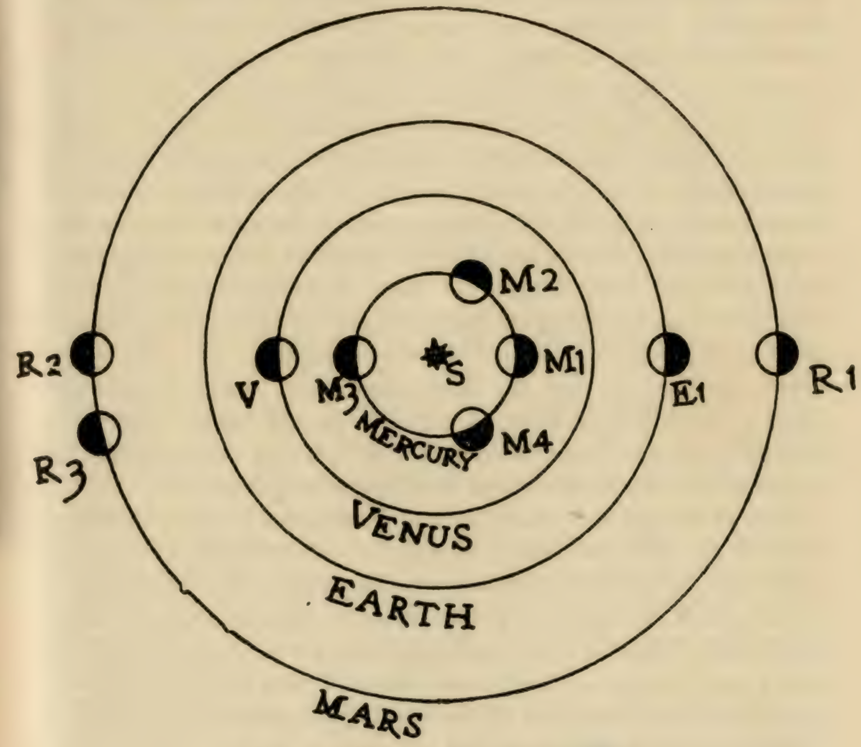


FIG. 3. Orbits of the inner planets

distances. Mars, the most distant member of the inner group, is on the average 141 million miles from the Sun; Jupiter, first of the giants, is 483 million miles off, far beyond the main asteroid zone; and Pluto, most distant of all, moves round the Sun at an average distance of 3,666 million miles – so far away that even a ray of light takes $5\frac{1}{2}$ hours to reach it.

As the planets are at different distances from the Sun, they do

not all take the same time to go once round it. In the case of the Earth, this period, known as the 'periodic time' or more familiarly as the 'year', is 365 days (more exactly, $365\frac{1}{4}$). Pluto, at the frontier of the Solar System, takes 248 times as long to complete one revolution. This is not only because it has farther to go, but because it moves less quickly.

Another of Kepler's discoveries was that the speed of a planet in its orbit depends upon its distance from the Sun. The greater the distance, the smaller the speed. If we whirl a stone round on the end of a piece of string, we must whirl more quickly if we shorten the string, and this gives us a good idea of the way in which the planets move, although the analogy is not really at all accurate. Pluto, the tortoise of the Solar System, crawls along at a mere three miles a second; if it moved much faster, it would break free from the Sun's control and make its own way into the depths of space. The Earth, so much closer in, moves at eighteen miles a second; little Mercury, a mere 36 million miles from the Sun, has to scurry along at thirty miles a second. With its small orbit and rapid movement, Mercury completes one revolution every 88 days, so that the Mercurian 'year' would seem very short to us. An Earth-boy of eighteen would be 75 'years' old according to the Mercurian calendar. On the other hand, he would be a mere babe-in-arms by Plutonian reckoning!

Two of the planets, Mercury and Venus, are closer to the Sun than we are, and there are a number of difficulties in the way of observing them. To begin with, we can never see them against a really dark sky, as they always lie in the same general direction as the Sun; Venus is large and comparatively near, but to the unaided eye Mercury is not an easy object. It can only be glimpsed now and then, low down in the east just before the Sun rises or low in the west just after sunset.

In Fig. 3 it will be convenient to imagine that both Sun and Earth are stationary – the Sun at S, the Earth at E1. M1, M2, M3 and M4 represent Mercury in four different positions in its orbit. At M1 Mercury will be almost directly between the Earth and the Sun; it will therefore seem very close to the Sun in the sky, and will be effectively drowned in the solar glare. (If the three bodies are exactly lined up, Mercury will be seen in front of the Sun's bright disk; this is known as a 'transit', but does not often occur, as Mercury's orbit is somewhat tilted with respect to ours.) This position, M1, is known as 'inferior conjunction'.

As Mercury moves on in its orbit, it reaches a position in which it forms a right angle with the Earth and Sun. It is then at its maximum apparent distance from the Sun (M2), and can appear quite a conspicuous object. Strangely enough, however, we cannot see all of Mercury when it is at position M2, but only half of it. This is because Mercury shines merely by reflected sunlight, and has no light at all of its own.

Obviously the Sun can only light up half of Mercury at once. The 'day' half of the planet shines; the 'night' half does not. At inferior conjunction, M1, Mercury's black or night side is turned towards us, and so the elusive little planet would be invisible even if it were not in the same line-of-sight as the Sun. At M2 half the day side is turned towards us, and so Mercury appears as a perfect half in our telescopes. This is known as 'dichotomy', a word which is derived from the Greek and means, literally, 'cut in half'. Between M1 and M2 the planet appears as a crescent, just as the Moon does when it makes its first appearance in the evening sky.

Between dichotomy, at M2, and 'superior conjunction', at M3, Mercury grows from a half into a 'gibbous' form, i.e. between half and full; but by the time M3 is reached, and the day half is wholly turned towards us, the planet is back in the same line-of-sight as the Sun, and has vanished in the glare. After an interval it reappears in the morning skies, and reaches greatest elongation again at M4, once more dichotomized or cut in half. As it narrows to a crescent it races back towards the Sun in the sky, and returns to inferior conjunction at M1.

Venus behaves in exactly the same way as Mercury, but is much larger and closer to us, so that it appears very much brighter. In fact, Venus is the most brilliant object in the sky apart from the Sun and Moon, and it is a great pity that we can never see it perfectly full. It is clear why this is the case. At full phase, Venus is at superior conjunction (V), and almost directly behind the Sun in the sky.

The remaining planets are more distant from the Sun than we are, and consequently more convenient to observe. Only Mars is shown in Fig. 3, but may be taken as typical of all the rest.

Obviously, no planet outside the Earth's orbit can ever undergo inferior conjunction, since it can never pass between Sun and Earth. At the corresponding position in its orbit, Mars, in position R1, is certainly lined up with the Sun and Earth; but this time the Earth is in the middle, with Mars opposite to the Sun in the sky and consequently well placed for observation. This is called 'opposition', and in the case of Mars occurs about every two years. To a Martian observer the Earth would appear to be at inferior conjunction.

Like Mercury and Venus, the outer planets can pass into superior conjunction. Mars is shown in this position at R2. It is then almost behind the Sun as seen from the Earth, and is consequently drowned in the solar rays.

The reason why Mars only comes to opposition every other year is because both it and the Earth are moving. The Earth takes approximately 365 days to make one complete revolution round the Sun, and if we start with the positions shown in Fig. 3, with the Earth at E1 and Mars at R1, the Earth will have returned to its original place after an interval of 365 days. Mars, however, has a longer periodic time – 687 days – and will not have arrived back at R1. It will only have travelled as far as R3. The Earth has to catch it up; and on the average it takes 780 days to do so, so that we can only observe Mars under good conditions every alternate year. The interval between successive oppositions is known as the planet's 'synodic period'.

Conditions are not quite the same for the more distant planets. They move so slowly compared to the Earth that they are much easier to catch up. Consequently, Jupiter and the other giants have shorter synodic periods, and come to opposition at intervals of little over a year.

A further point of interest about the planetary orbits is that they all lie in practically the same plane, so that we are not far wrong when we draw them on a flat sheet of paper. This means that the planets can never wander near the celestial poles in the sky; they must keep close to the 'ecliptic', which is the name given to the apparent path of the Sun among the stars. Of course, the coincidence is not exact – otherwise both Mercury and Venus would appear to transit the Sun's disk at each inferior conjunction – but none of the planets, apart from Pluto and some of the asteroids, have orbits which are markedly inclined to that of the Earth.

A brief account of the planetary motions, such as this, can give little indication of the enormous problems which confront the mathematical astronomer. Each planet pulls upon its fellows, producing perturbations in their movements; the satellites of the major planets have also to be taken into account; and there are any number of uncertain quantities to be considered, such as the 'relativity' effect predicted by Einstein – which has turned out to be quite important in the case of Mercury, though it is impossible to describe adequately without recourse to higher mathematics.

On the whole, there can be no doubt that astronomers have succeeded wonderfully well in their attempts to solve the mysteries of celestial mechanics. They can predict the position of any planet not merely for a day or a month ahead, but for a century ahead if need be; and though uncertainties are bound to remain, the planets have yielded up many of their closely-guarded secrets of motion. Perhaps this is as well. Before long man will take his initial leap into the depths of space; and if the mathematicians err, the first interplanetary travellers will have only the very slimmest chance of survival.

CHAPTER 4

Mercury

Long ago, so long ago that we do not know just when, the ancient peoples noticed a bright star which could sometimes be seen low down in the western sky just after the Sun had set. It was not an ordinary star; it did not correspond in position with any of the so-called 'fixed stars' so familiar to the old shepherd-astronomers, and so it could only be a planet. Later, it was identified with a similar planet seen from time to time in the eastern sky just before sunrise. The Greeks named it in honour of the messenger of the gods, and certainly the little planet is always elusive and hard to catch; there is even a story that the great astronomer Copernicus died without seeing it at all, though as a matter of fact this seems rather unlikely.

Mercury revolves round the Sun at an average distance of 36 million miles, and is the closest-in of the planets. One known asteroid (Icarus) and a large number of comets have the temerity to approach closer to the solar surface, but no other large bodies move in those torrid regions. Just under a century ago, however, an intra-Mercurian planet was believed to exist; its presence was regarded as well established, and it was even given a name – Vulcan. The story of this so-called 'discovery' is most interesting, and a first-class example of how even the most brilliant scientists can be misled.

The Director of the Paris Observatory at that time was named Le Verrier. He was probably the greatest astronomer of his day, and had been personally responsible for adding a new planet to the Solar System. He had discovered that Uranus, then the most remote planet known, was not moving according to theory; something was pulling it out of its path, and Le Verrier's calculations led to the tracking-down of the disturbing planet, now named Neptune. In 1860, some fifteen years after this triumph, Le Verrier arrived at a similar result for Mercury; the 'messenger of the gods' was not where he should be, and it seemed reasonable

to assume that this was due to the attraction of an unknown intra-Mercurian planet.

This was not actually the case. Many years later, Einstein's theory of relativity cleared up the discrepancy without involving an unknown planet at all. But at about the time that Le Verrier finished his calculations, a French doctor named Lescarbault wrote to say that he had watched an intra-Mercurian planet passing in transit across the face of the Sun.

At some inferior conjunctions both Mercury and Venus do pass across the Sun. and presumably any inner planet would do the same – which, incidentally, would be almost the only hope of observing it at all. Le Verrier made haste to visit Lescarbault, and despite the doctor's rather strange methods (for instance, he recorded time by an old watch that lacked its second hand, and recorded his observations with chalk upon wooden boards, planing them off when he had no further use for them), Le Verrier decided that a new planet had indeed come to light. He named it 'Vulcan', and calculated that it was 13 million miles from the Sun, with a periodic time of 19¾ days and a diameter of something like a thousand miles. He also worked out the times of future transits.

However, Vulcan has never since been seen, and it is now quite certain that what Lescarbault saw – if, indeed, he saw anything – was not a planet. It may have been a sunspot, but it is interesting to note that Liais, in Brazil, had been observing the Sun at the exact time of Vulcan's supposed transit and had seen nothing at all.

Interest was rekindled for a time in 1878, when there was a total eclipse of the Sun. At a total eclipse the Moon passes directly in front of the Sun and blots out the bright solar disk, so that stars can be seen for a few minutes in the middle of the day; and two American observers, Watson and Swift, believed that they had recorded various unidentified starlike objects. However, Watson's and Swift's observations agreed neither with the predicted Vulcan nor with each other, and little reliance can be placed upon them. It is now quite definite that Vulcan does not exist, and that Mercury is the first planet we encounter in our journey outward from the Sun.

Mercury is not at all easy to observe, partly because it always

seems inconveniently close to the Sun and partly because it is small and distant. It is not a great deal larger than the Moon (its diameter is about 3,100 miles), and it is two hundred times as far off. There is the further difficulty that when it is at its closest to

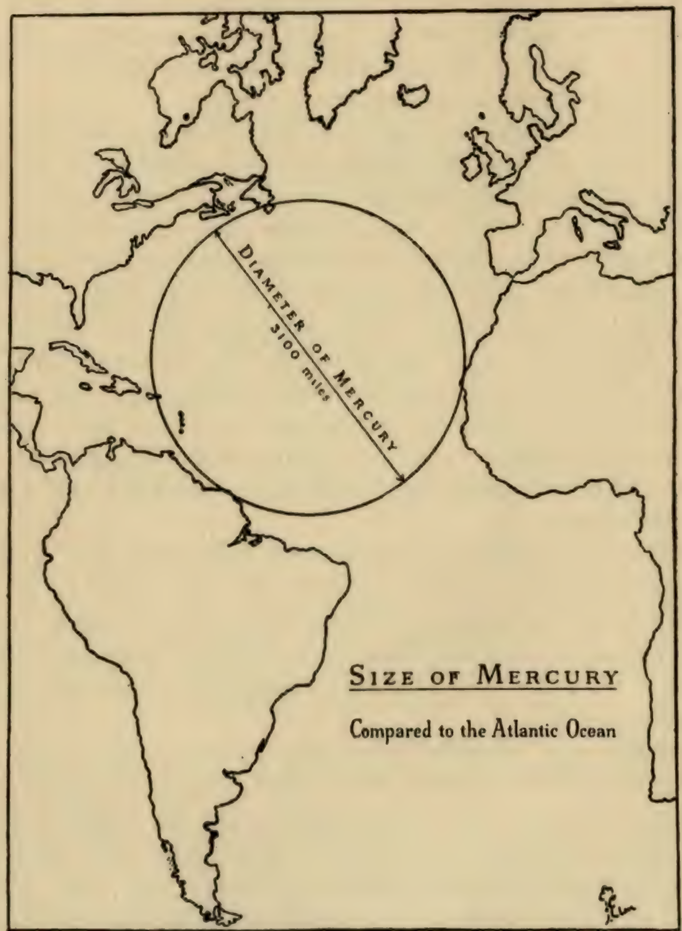


Fig. 4. Size of Mercury, compared to the Atlantic Ocean

the Earth, at inferior conjunction, it cannot normally be seen at all, as its non-luminous night hemisphere is then turned towards us. All things considered, it is not surprising that our knowledge of its surface features remains rather slight.

The first serious telescopic observations of Mercury were made towards the end of the eighteenth century. Sir William Herschel, discoverer of the planet Uranus and an observer of genius, could detect almost no surface markings even with his great telescopes; more positive results were obtained by a German amateur, Johann Schröter, who constructed the first proper chart of the planet and believed, quite reasonably, that he had detected definite and permanent markings. Unfortunately Schröter, though a very honest and painstaking observer, was no draughtsman, and some of his reported 'discoveries', such as that of a mountain eleven miles high, are rather hard to credit. It is difficult to believe that he could succeed where Herschel had failed.

It was left to a keen-eyed Italian astronomer, Schiaparelli, to draw up the first reliable map of Mercury. Rather than wait for sunset, when the planet was of course low in the sky, Schiaparelli made most of his observations in broad daylight; and between 1881 and 1889 he plotted a number of dark, well-defined streaks and patches against the generally pinkish background. He also attacked the problem of Mercury's rotation period, i.e. the length of its 'day'.

Schröter's value for this had been 24 hours, almost the same length as the Earth's, but Schiaparelli's work led him to the remarkable conclusion that Mercury kept one hemisphere permanently turned towards the Sun, with the other bathed in perpetual night. This would mean that Mercury revolved once on its axis in exactly the same time that it took to go once round the Sun – approximately 88 terrestrial days.

If Mercury had no axial spin at all, each part of its surface would see the Sun at some period, as can easily be shown by means of a simple experiment. Place a chair in the middle of a room and represent Mercury by your head. Now look at the chair and walk in a circle round it. If you want to keep your face towards the chair, you must turn slowly as you walk (otherwise the back of your head will be pointing to the chair after you have gone half-way round). By the time you have come back to your starting-point, you will have turned once; and this is how Schiaparelli considered that Mercury behaved.

Recent studies have shown that he was right, and that consequently the terms 'day' and 'night' have no real meaning so far

as Mercury is concerned. One hemisphere is perpetually scorched by the solar rays, while no gleams of sunlight ever penetrate to the far side. Truly, the innermost planet is a strange world.

There is a perfectly logical reason for this curious state of affairs. In the early days of its existence as a separate body, Mercury must have been hot and plastic, with a relatively rapid rate of rotation. Just as the Moon raises tides in the oceans of the Earth, so the Sun raised tides in the viscous body of Mercury; material was heaped up in a bulge in the Sun's direction, and as Mercury spun on its axis the Sun did its best to keep the bulge stationary. The result was that Mercury's rate of rotation was steadily slowed down until, relative to the Sun, it had ceased; the day became equal to the year, and the tidal bulge remained permanently pointing to the Sun.

Perhaps the most valuable observations of Mercury yet made have been carried out by French observers – first by E. M. Antoniadi and more recently by Dr. Lyot and Dr. Dollfus. Antoniadi worked with the largest refractor in Europe, the 33-inch telescope at the Observatory of Meudon (with which I have had the privilege of making extensive lunar observations, leaving no doubt in my mind that it ranks with the finest instruments in the world), and Lyot and Dollfus with the 24-inch refractor of the Pic du Midi Observatory, situated high in the Pyrenees above the densest and most troublesome layers of the Earth's atmosphere.

Antoniadi's chart, reproduced here, agreed reasonably well with Schiaparelli's, and he also gave names to the light and dark areas which have now passed into general use. Like Schiaparelli, he made most of his observations when the Sun was above the horizon and Mercury high in the sky. Antoniadi's observations were continued, from 1940, by Lyot – whose sudden death in 1952 was such a tragic loss to astronomy – and by Dollfus, whose 1950 chart is perhaps the most detailed yet drawn. Another excellent map is that of Dr. Werner Sandner, one of Germany's leading planetary observers, and this too is reproduced here.

However, we must admit that our knowledge of the 'geography' of the planet is still anything but complete. Large telescopes are needed to show anything definite. I have occasionally seen the most conspicuous of the shadings with a small refractor under good conditions, but this is possibly only because I know just

where to look for them. Still, there is great satisfaction even in catching sight of the fleet-footed little world as it glimmers shyly out of the twilight sky.

We can never see 'full Mercury', as the planet is then at

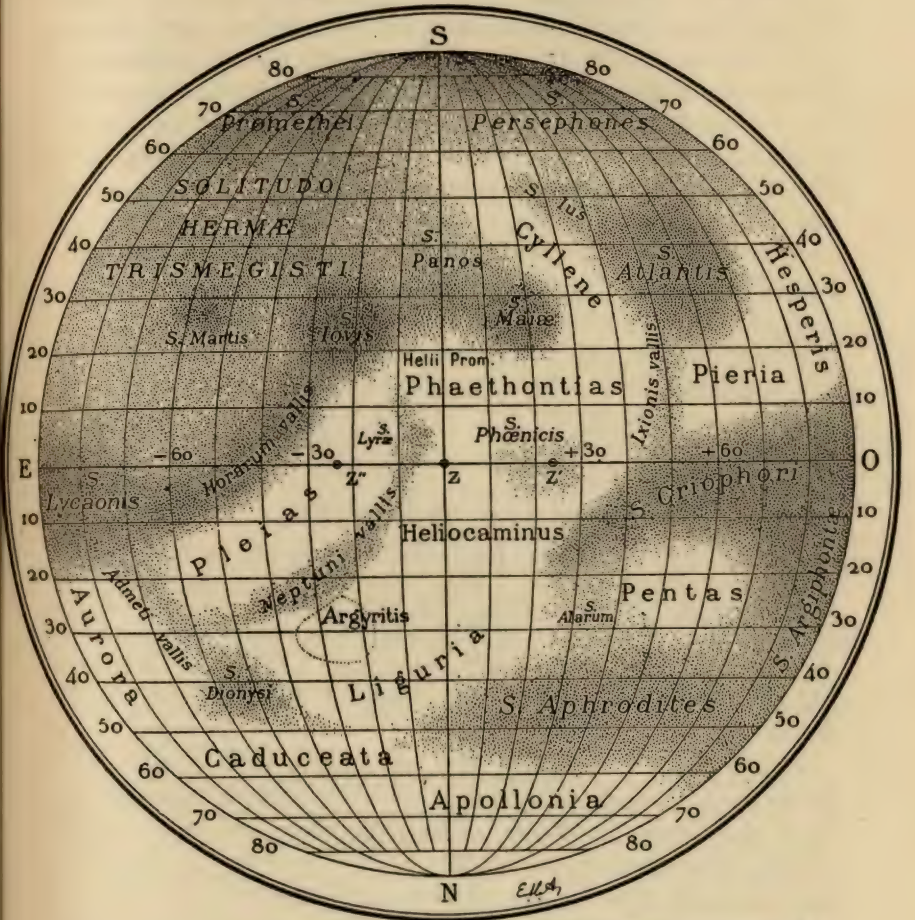


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FIG. 5. Antoniadi's chart of Mercury

superior conjunction and on the far side of the Sun. When apparently most conspicuous to the naked eye, Mercury shows as a crescent or half. The phases are quite obvious even with a small

telescope, and it is interesting to study the 'cusps' and 'terminator', as unusual features may be glimpsed every now and then.

The terminator is the boundary between the sunlit and night hemispheres, and should not be confused with the 'limb', which is merely the edge of the apparent disk. The difference is shown in Fig. 6, in which the terminator is dotted and the limb drawn as a continuous line. In the case of the Moon, the terminator always appears rough and broken, with mountain summits catching the sunlight while the valleys below are still bathed in shadow; Mercury is so far off that the terminator appears smooth, but occasional projections and irregularities are seen, which lends support to the theory that the surface is mountainous in character. The horns of the crescent are known as the 'cusps', and as long ago as 1800 Schröter noted that the upper or

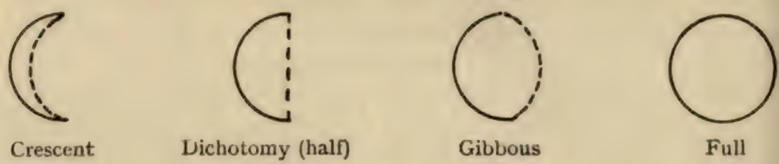


FIG. 6. Limb and Terminator

southern[1] cusp was usually blunter than the northern. Reference to the charts will show why. The southern part of the disk is much darker than the northern, and in the south-west can be seen a large grey area which Antoniadi named the Solitudo Hermæ Trismegisti – "The Wilderness of Mercury the Thrice Greatest".

The Mercurian markings are grey, fairly well defined, and permanent, showing up against a generally pinkish background. As to their exact nature we can only speculate; but the existence of lofty mountains seems probable, even if we reject the towering heights which Schröter thought he had discovered.

For many years it was uncertain whether or not Mercury possessed any sort of atmosphere. A thick air-mantle was not to be expected, because of the low value of Mercury's 'velocity of escape', a term which requires some explanation.

[1] An astronomical telescope gives an inverted picture, so that in all astronomical drawings the south is shown at the top, west being to the right.

If a ball is thrown into the air it will rise to a certain height, stop, and come down again; the harder it is thrown, the faster it will go and the higher it will soar. If it could be thrown upwards at a speed of seven miles a second, it would never return at all. The Earth's drag is powerful, but not all-powerful; and a body starting off at seven miles a second would break free for ever. This critical speed, seven miles a second, is the Earth's 'velocity of escape'. If the particles of air moved more quickly than this, they too could leave the Earth and leak away into space.

This has actually happened in the case of the Moon, which has a smaller mass and a much lower critical velocity ($1\frac{1}{2}$ miles a second), with the result that almost all the lunar atmosphere has now departed. Mercury is a borderline case. There is some uncertainty about the planet's mass, and hence the escape velocity; but the most probable value is about $2\frac{1}{4}$ miles a second, so that Mercury is only capable of holding on to the more leisurely particles of atmosphere. We must therefore expect any 'air' to be thin, and quite unlike ours in composition – made up probably of heavy, slow-moving gases such as carbon dioxide, the gas which we see dissolved in soda-water.

It is easy to prove, observationally, that the Mercurian atmosphere is not appreciable. From time to time the planet passes in transit across the Sun, and it then appears as a sharply-defined dark circle – as in Fig. 7A, a drawing made by Dr. H. P. Wilkins on 1914 November 6, at the moment when the planet was just appearing against the solar limb. A dense layer of air around Mercury would cause a blurred appearance, as ic actually the case for Venus.

Mercury's orbit is inclined to ours at an angle of seven degrees, and transits are therefore infrequent; at inferior conjunction, the planet usually passes above or below the Sun in the sky. The last transit took place on 1953 November 14; the next will be on 1960 November 6, 1970 May 9, 1973 November 9, 1986 November 12 and 1999 November 14. (Transits can only occur in May or November.) At such times the planet appears as a small black dot, too inconspicuous to be seen without the aid of a telescope. Strange appearances have been reported during past transits, but it seems that all these must be put down to defects in eyes or instruments.

On the other hand, both Schiaparelli and Antoniadi agreed that the dark markings of Mercury were often veiled by whitish clouds, and Antoniadi even stated that these clouds were "more frequent and obliterating than those of Mars". Needless to say, there was never any suggestion that the clouds were in any way like those of the Earth; water-droplets on Mercury would be as short-lived as snowflakes in a blast-furnace. Until very recently, the existence of clouds of some sort was regarded as definitely established; but observations made at the Pic du Midi led Dollfus, in 1953, to state that he "had never seen a modification of the aspect of the surface definitely attributable to atmospheric

A B

FIG. 7. Transits of Mercury: (A) 1914, Nov. 6; (B) 1953, Nov. 14 (3-inch O.G., direct vision; H. P. Wilkins)

clouds", and that the evidence in favour of them was far from conclusive, so that the whole question seems to be open once more.

Dollfus has, however, detected the presence of a tenuous atmosphere. It is thin – the ground density cannot exceed $\frac{3}{1000}$ of the Earth's – and corresponds to what is normally described as a laboratory vacuum; a barometer would record a pressure of only about one millimetre, which is negligible. We can only guess at its composition, but carbon dioxide seems to be a strong possibility, as the feeble pull of Mercury would be sufficient to hold it down.

Even this thin air-mantle would probably be capable of supporting dust, and if Antoniadi's clouds really exist they are almost certainly veils of dusty material. However, it is not easy to see just how they could spring up. The winds in the tenuous atmosphere would be unable to cause violent dust-storms, and neither are volcanic eruptions to be expected upon a world so dormant as Mercury. Still, it is pointless to speculate upon the origin of the clouds until we can be quite certain that the clouds themselves exist.

Mercury is so small and remote that its surface temperature is extremely difficult to measure with any accuracy. If we are right in believing that one hemisphere is turned perpetually towards the Sun (and the observations by Lyot and Dollfus seem to leave no room for doubt upon this score), the heat there must be terrific, quite beyond anything in our experience. Measurements made by Pettit and Nicholson at the Mount Wilson Observatory, in California, confirm this. At the centre of the sunlit hemisphere, the temperature at perihelion rises to some 700° F. This is torrid indeed, hot enough to melt lead or tin; and we may be quite sure that no space-travellers of the far future will ever venture there.

In sharp contrast, the night side of Mercury is bitterly cold – possibly the coldest place in the Solar System. The atmosphere is quite incapable of carrying any heat round to the regions where no solar rays penetrate, and in consequence the temperature there cannot be very far above absolute zero. Remote Pluto, so far from the Sun that it is bathed in eternal twilight, certainly spins on its axis in a shorter time than it takes to go once round the Sun, so that every part of its surface is periodically illuminated; and this alone must raise the temperature above that of the sun-starved hemisphere of Mercury. It is not, therefore, correct to say simply that Mercury is the hottest of the planets. It is also the coldest.

If Mercury revolved round the Sun at a uniform speed, with its day equal to its year, exactly half the planet would be permanently sunlit. Actually the situation is rather more complicated. Undoubtedly the planet spins on its axis at a constant speed, but its speed of motion round the Sun is not constant. Mercury's orbit is much more elliptical than ours, and the dis-

tance from the Sun varies from 28½ million miles at perihelion to 43½ million at aphelion. The smaller the distance, the greater the orbital speed, in conformity with the traffic laws of the Solar System; and whereas Mercury hastens along at some 36 miles a second when near perihelion, the speed drops to only 24 miles a second near aphelion. The axial rotation can, therefore, get 'out of step'. Sometimes the rotation is a little ahead of itself with respect to the planet's position in its orbit, sometimes a little behind.

The result is that the Sun must seem to sway in the Mercurian sky, and there is a fairly wide belt, between the region of permanent day and the region of permanent night, where the Sun will sway alternately just above and just below the horizon. This 'twilight zone' will be the least inhospitable part of Mercury, and here, if anywhere, the explorers of the future will land.

It is clear, however, that Mercury is not likely to be visited for many centuries yet. Even when Mars and Venus have been conquered, Mercury will remain unexplored. It never approaches the Earth much within 50 million miles, so that at reasonable speeds the round trip to it would take over a year. Moreover, the planet would give its visitors no welcome when they arrived. With its parched rocks, torrid mountains and thin, useless carbon dioxide atmosphere, Mercury is not an attractive world.

What would we see, supposing that it was possible for us to land in the twilight zone of Mercury?

High, cracked mountains casting immense shadows across the barren surface; a vast, blazing sun low down near the horizon; an eternal desert which never has, and never will, know life. All is silent; sound-waves are carried by atmosphere, and the thin air-coating of Mercury is too tenuous to carry even the whisper of a sound. A dazzling planet high in the sky, cloud-covered Venus; a second planet, shining with a strong blue-green light and attended by a starlike companion – the Earth and its Moon. But we would not linger for long. Mercury is a lifeless world, and no human power can waken it from the sleep of death.

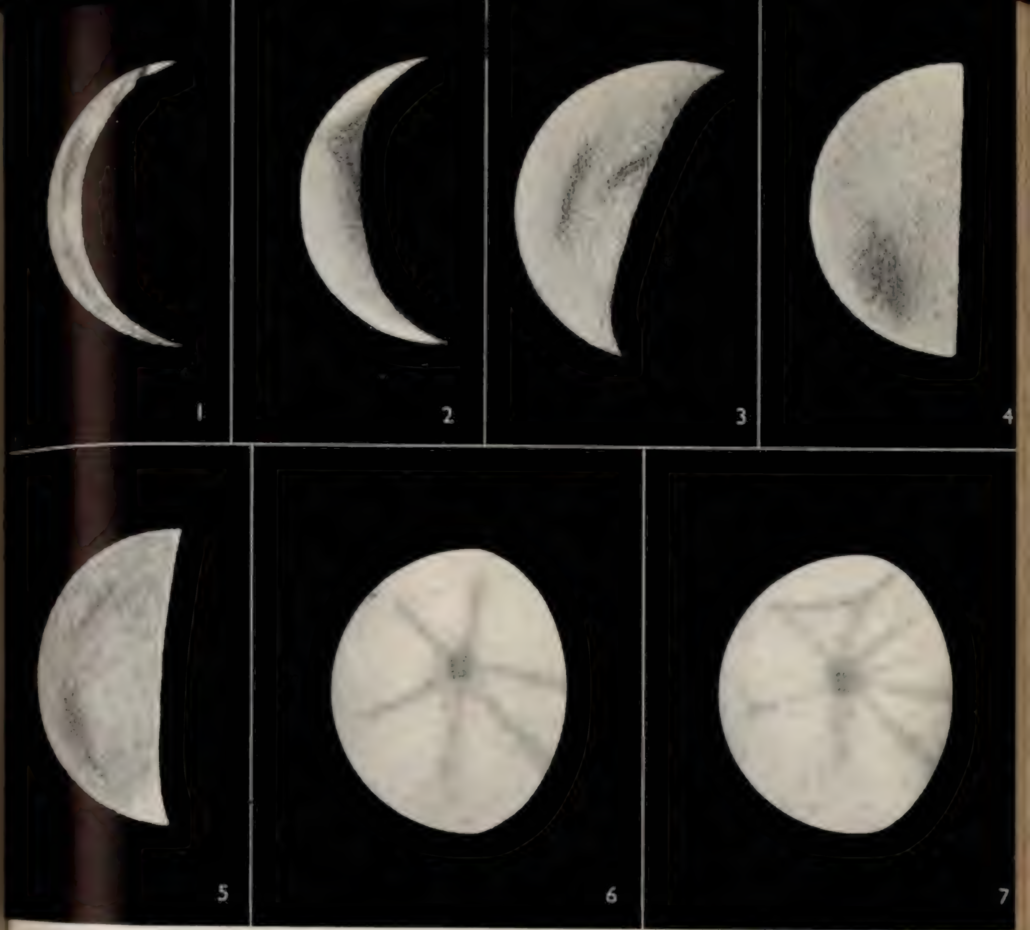


PLATE V. Seven drawings of Venus (the linear features shown by Baum are absent from the other drawings—see text)

1. 1953, Mar. 8, 18h., 12½-inch refl. ×250, Patrick Moore
2. 1953, Mar. 17, 3-inch O.G. ×150, F. C. Butler
3. 1945, Feb. 14, 19h., 6½-inch refl. ×200, R. L. T. Clarkson
4. 1953, Jan. 18, 17h. 40m., 3-inch O.G. ×130, Patrick Moore
5. 1953, Feb. 2, 19h. 10m., 12½-inch refl. ×180, Patrick Moore
6. 1951, Mar. 23, 18h. 25m., U.T., 3-inch O.G. ×100, R. M. Baum
7. 1951, Mar. 27, 19h., 3-inch O.G. ×100, R. M. Baum,

PLATE VI. Venus (photograph, Mount Wilson and Palomar Observatories). Taken with the 200-inch Hale Reflector

CHAPTER 5

Venus

It is quite refreshing to turn from the dead, inhospitable Mercury to Venus, the second planet from the Sun, which could hardly present a greater contrast. It moves in much the same manner as Mercury, showing phases, and appearing sometimes as a morning and sometimes as an evening star; but there the resemblance ends.

Originally the morning and evening stars were thought to be different bodies, and they were even given different names, Phosphorus and Hesperus; but as long ago as B.C. 500, Pythagoras, the great Greek geometer, realized that the two are identical. Venus is in fact so brilliant that it must have been known even at the dawn of history, and Homer, the blind poet whose works will live for ever, sang of "Callistos, the Beautiful".

Venus is considerably closer to the Sun than we are. Its average distance is 67 million miles, and this hardly varies at all, as the orbit is almost perfectly circular. At inferior conjunction, Venus may approach to within 25 million miles of the Earth, and is therefore our nearest neighbour in the Solar System, apart from the Moon and an occasional comet or asteroid. The periodic time is 225 days, and therefore an Earth boy of fifteen would be 24 'years' old according to the Cytherean[1] calendar; and the orbital speed, $21\frac{3}{4}$ miles a second, is correspondingly greater than ours.

Mercury is shy and elusive in the twilight, but there is nothing shy about Venus, which is brilliant enough to be seen in broad daylight under favourable conditions and is much brighter than anything else in the sky apart from the Sun and Moon. This is partly because Venus is closer than Mercury or Mars, but also because it is larger. In fact, Venus is almost a twin of our own

[1] This adjective (from Cythera, one of the names for the mythological Goddess of Love) seems preferable to the more common but decidedly ugly 'Venusian'.

globe. The diameter is about 7,700 miles, compared to the Earth's 7,926; and the mass and escape velocity are about the same, so that if we landed on Venus we should not feel appreciably lighter than we do at home.

Unfortunately, we cannot see Venus at all when it is at its closest. This is at the time of inferior conjunction, when the 'night' side is turned towards us and, in any case, the planet is very near the Sun in the sky. Venus appears brightest when at the crescent stage, with about 30 per cent. of the daylight hemisphere turned towards us; this is because the planet is then closer than when more fully illuminated. The 'full Venus', approaching superior conjunction, is small and shrunken; and at the actual point of superior conjunction Venus is on the far side of the Sun, at a distance of some 160 million miles. The photographs in Plate III, which were taken by E. A. Whitaker at Greenwich Observatory, show the apparent size of Venus at different phases.

When favourably placed, Venus may set as much as five and a half hours after the Sun; it can then be seen against a dark background, appearing like a small, glittering lamp in the sky. It has even been known to cast shadows. I have a personal recollection of this. It was on a Sussex beach late one evening; Venus blazed down from a velvety sky, and I could see my shadow thrown beside me on to the sand.

Venus is so magnificent to the unaided eye that it comes as a surprise to learn that it is a great telescopic disappointment. In place of the mountains, valleys, oceans and plains that we might reasonably expect to see, all that we can make out is a bright, whitish, almost blank disk; and there is no doubt that what we are looking at is not the actual surface at all, but merely the top of a deep, cloudy atmosphere. This atmosphere is so opaque that we are quite unable to see through it, try though we may, and consequently we can only guess at what lies beneath. We are in a far worse position than that of a man trying to see across Oxford Circus in a dense London fog. The fog will eventually clear, even in an English winter; the atmosphere of Venus never does.

The most striking thing about Venus, as seen through a telescope, is its phase. Even a very small instrument will show the

half or crescent form, and the fact that Venus behaves in this way has been known ever since 1610, when Galileo first looked at the planet through his crude telescope. Strangely enough, however, the predicted phase is not always accurate, and this is particularly noticeable near half-phase.

The point at which Venus becomes a perfect half is known as 'dichotomy'. The movements of the planet are known with great accuracy, and dichotomy can thus be predicted to within a few minutes, but the difference between theoretical and actual dichotomy may amount to many days. In the winter of 1953, for instance, dichotomy was over a fortnight early. It should have occurred on February 3; I recorded Venus as a perfect half on January 18, whereas on February 2, still before the predicted time of half-phase, the terminator was noticeably convex (Plate V). On the other hand, dichotomy in late 1951, when Venus was a morning star and therefore waxing, was well behind time. The predicted date was November 14, but the American observer S. C. Ventner did not record a straight terminator until November 26.

Observations of this kind are not new. Schröter first noticed the discrepancies a hundred and fifty years ago, and explained them (not very convincingly) by the falling-off of light near the terminator. Shadows cast by tall mountains across Venus' surface have also been suggested. The true explanation is still not definitely known, but we can at least be sure that it is due to some sort of optical effect; the deep, dense atmosphere of Venus is responsible.

When Venus is near inferior conjunction, and therefore almost at its closest, it appears as a large, slender crescent, and from time to time roughnesses and irregularities have been noticed in the terminator. We know that the terminator of the Moon is always broken and jagged, because the surface is uneven; the top of a peak will always catch the sunlight while the lower-lying country at its base is still bathed in shadow. Similar appearances in the terminator of Venus might lead us to believe that there are mountains there, too.

On three occasions between 1789 and 1793, Schröter described a bright, starlike point clear of the terminator of the crescent Venus, and attributed it to a peak. He measured it carefully,

and calculated that it rose to a height of no less than $27\frac{1}{2}$ miles above the surface![1] As Venus is almost the Earth's twin in size and mass, and our own mountains rise to less than six miles above sea-level, a gigantic peak of this sort upon Venus does not appear at all likely; but there is no need to assume anything of the sort, even if the accuracy of Schröter's observation is accepted. A lofty cloud catches the sunlight just as brilliantly as a peak does, and the 'detached starlike point' may therefore have been nothing more than a particularly high cloud.

Other projections and indentations in the terminator of Venus have been seen frequently since Schröter's time, and some persist for days on end. For instance, I followed one from March 4 to March 11, 1953. The planet was then an evening star, and actually reached maximum brilliancy on March 8; in my $12\frac{1}{2}$-inch reflector, a dent in the terminator not far from the southern cusp was perfectly plain (Plate V). Many other observers have recorded similar phenomena.

What causes these irregularities in the terminator? Some, at least, may be due to contrast effects. A relatively dusky part of the disk, hemmed in near the terminator between two brighter patches, might appear as an indentation, whereas a bright patch between two darker areas would probably seem to project. High clouds may account for other projections, as well as detached points of the type seen by Schröter; and although it is quite possible that the Cytherean surface is mountainous, we have so far not the slightest proof.

The disk itself shows only vague, hazy features, and it is probably correct to say that Venus is one of the most difficult of all celestial bodies to observe – instead of being the easiest, as we would have every right to expect from its size and nearness. The markings visible can be divided broadly into two types, bright patches and dusky shadings.

The bright patches are ill-defined, and seldom last for more than a day or two. A number can be seen in the drawings in

[1] These statements of Schröter's were violently attacked by the great astronomer Sir William Herschel. Herschel's tone was in fact offensive, quite unlike his usual manner; but fortunately Schröter's reply was calm and courteous, and the two observers kept up a cordial correspondence for many years afterwards.

Plate V, but it is difficult to represent them as vaguely as they actually appear, and once again we must attribute them to mere cloud effects.

Very often the horns or 'cusps' of the crescent or half Venus appear considerably brighter than the rest of the planet. These cusp-caps have been intensively studied in recent years. Either cusp may have a cap, and each cap lasts for some time – perhaps as long as a fortnight. At times they may be really striking. For instance, on 1952 September 7, O. C. Ranck, in the United States, recorded a very bright, prominent southern cap, similar in appearance to a Martian one.

The polar caps of Mars are well known, and it is now certain that they are due to ice or snow. It is tempting to suggest that the Cytherean caps are similar in nature, but there are any number of difficulties in the way of accepting ice anywhere on Venus.

To begin with, we do not even know whether the cusp-caps mark the poles of Venus at all. The length of the 'day' is most uncertain, and the tilt of the axis of rotation may be unexpectedly large. For all we know, Venus' pole may lie in the middle of the apparent disk. On the other hand, the remaining planets (Uranus excepted) spin with their axes of rotation at moderate angles to the planes of their orbits – the angle in the case of the Earth is $23\frac{1}{2}°$ – and there is no reason to suppose that Venus is unusual in this respect.

T. L. Cragg, a leading American observer, is strongly of the opinion that the cusp-caps do indeed mark the poles of Venus; and this is endorsed by Dr. J. C. Bartlett, who adds:[1] "If this be so, there is no physical reason why the poles should not be covered with snow and ice . . . despite the closeness of Venus to the Sun." On this view, the caps are essentially similar to the icefields of the Earth or Mars.

My own view is somewhat different. All other observations indicate that the atmosphere of Venus is deep enough and cloudy enough to mask the surface completely, and consequently it would seem impossible to catch sight of the icefields even if they existed. Elevation of the poles upon a high table-land would not help; if the atmosphere is really hundreds of miles deep, as is

[1] *Strolling Astronomer*, Vol. 6, p. 17, 1952.

believed by H. McEwen,[1] we would have to increase the height of Schröter's reported 'mountain' by a factor of at least ten to make the snowy cap poke out. In any case, if snow existed on Venus it would periodically melt, and we would expect to find at least traces of water-vapour in the atmosphere – which is not the case. Altogether, the theory seems to be quite unacceptable, and we must look elsewhere for an explanation of the cusp-caps.

They may be due to contrast. This is possible, but on the whole unlikely, although the dark 'collars' to the caps, seen from time to time by many observers (including myself) may be due to this cause. If Cragg and Bartlett are right in believing that the cusps really do mark the Cytherean poles, as seems very probable, the caps may be caused by some peculiarity of the atmospheric circulation in the polar regions; but at the moment we have no definite information.

The dusky shadings of Venus are even more nebulous and indefinite than the bright areas. They are not difficult to see; as early as 1643 Fontana, one of the first of all planetary observers, drew them distinctly, and even a small telescope will show them. But although easy to detect, they are not at all easy to draw. They are extremely vague, and once again it seems that they are due to nothing more solid than drifting cloud.

Naturally enough, the early telescopic observers believed that Venus showed a solid surface, and an Italian astronomer named Bianchini even drew up a chart based upon observations made between 1727 and 1732; he thought that he had distinguished continents, oceans, promontories and straits, and that the markings were permanent. Undoubtedly he did detect shadings, but his 'continents' and 'oceans' are myths, so that his chart is of historical interest only.

Actually, the shadings of Venus alter in position from night to night. The appearance is seldom the same for two consecutive evenings (or mornings), and therefore any attempt to draw up a chart of the surface is doomed to failure. This was the opinion of E. M. Antoniadi, who made a long series of observations with the

[1] Mr. McEwen's opinions must carry a great deal of weight, as he has undoubtedly more observational experience with regard to Venus than anyone else now living. He was appointed Director of the Mercury and Venus Section of the British Astronomical Association in 1895, when the Section was first formed, and is still Director.

Meudon telescope, and is also the view held by Dollfus, who has recently been studying Venus at the Pic du Midi. In fact, the only leading astronomer of the present century to hold a contrary view was Professor Percival Lowell, whose work is certainly worth describing.

Lowell, who began his career as a diplomat (he was American Councillor for Korea for some years) and became an astronomer, is best remembered for his theories about Mars, though as a matter of fact his best work was probably in the realm of mathematical astronomy. Lowell believed Mars to be covered with a network of straight, narrow canals, the work of intelligent beings; and he constructed an observatory at Flagstaff, under the clear skies of Arizona, primarily to observe the planet. His main telescope was of considerable size, a 24-inch refractor, and between 1892 and his death, in 1916, he made thousands of observations not only of Mars but also of other planets. His drawings of Venus are remarkable, to say the least of it. Instead of the soft, nebulous shadings of McEwen and the other observers of the time, he recorded hard, sharp, linear features, and described them as follows:[1]

"The markings are long and narrow, but unlike the finer markings on Mars, have the appearance of being natural and not artificial. . . . The markings, which are a straw-coloured grey, bear the look of being ground or rock, and it is presumable from this that we see simply barren rock or sand weathered by æons of exposure to the Sun. I have seen the markings when their contours had the look of a steel engraving."

Lowell thus rejected the whole idea of a dense, all-concealing Cytherean atmosphere, and reverted to the old theory of a visible rock surface. Unfortunately, his linear markings have never since been seen by any observer equipped with a telescope of comparable size. It is also curious to note that he seldom used the full power of his telescope; he generally stopped down the aperture to 18 inches, which seems to indicate something wrong either with the instrument or (more probably) with his own eyes. I have made extensive lunar and some planetary observations with the Meudon refractor, which was the instrument used by Antoniadi for nearly all his important work; but although the skies of

[1] Monthly Notices of the Royal Astronomical Society: LVII, 148, 1897.

France are not nearly so transparent as those of Arizona, and the Meudon telescope is larger than Lowell's, there has never been any necessity to stop down the aperture. Altogether, Lowell's drawings of Venus must be regarded with grave suspicion.

Although Lowell's theories are now universally rejected, there are some contemporary observers who record linear features on Venus, though not in the hard, narrow form shown by Lowell. One of these is R. M. Baum, some of whose drawings are reproduced in Plate V. Why, then, should the straight markings be missed by such expert and well-equipped observers as Antoniadi and Dollfus?

Undoubtedly the streaky markings have a basis of reality; and a possible explanation is that large telescopes are powerful enough to break down roughly-aligned shadings into distinct patches. In fact, the linear features can be seen only with modest instruments; larger telescopes show them in their true guise.

It has sometimes been stated that "the larger the telescope, the less one sees on Venus", the reason given being that although a high magnification increases the size of the apparent disk, it also increases the tremors due to the Earth's unsteady atmosphere. However, this seems to me unreasonable, as I have demonstrated to my own satisfaction by a simple experiment. On 1953 March 1, under excellent atmospheric conditions, I drew Venus first with a 3-inch refractor and then with my 12½-inch reflector. Two diffuse shadings were seen, just perceptible with the small telescope but perfectly obvious with the large one. This experiment has been repeated on numerous occasions, and the result is always the same; the genuine features of Venus, the diffuse shadings and nebulous white patches, as well as the occasional deformations of the terminator, are only seen clearly with large apertures under good conditions.

Apart from Lowell, who, incidentally, recorded sharp lines not only upon Venus but upon nearly every other heavenly body that he observed (for instance, Mercury and the four large satellites of Jupiter), the only observers to record sharp linear markings on Venus are those equipped with inadequate telescopes. It seems probable, therefore, that they are due to optical illusion. The human eye is very easily deceived.

Photography is of no help in clearing up the mystery; in fact,

most photographs of Venus show no details at all. The best results have been obtained by taking photographs in light of short wavelength; and in this way F. E. Ross, at Mount Wilson, has recorded definite markings on Venus, some of them vaguely streaky.

Light of short wavelength has little penetrating power, and consequently it seems that the features shown on Ross's photographs are high-altitude clouds, floating in the upper atmosphere of Venus. At all events, it is now certain that the 'steel engravings' of Lowell do not exist.[1]

One of the chief aims of observing the shadings of Venus has always been to deduce some sort of rotation period. Unfortunately, the clouds shift so rapidly that all attempts up to the present time have ended in failure, and we still do not know the length of the 'day' upon our sister planet.

Cassini, a celebrated Italian observer, attacked the problem in 1666, and obtained a value of 23 terrestrial days; but in the following year he amended this to 23 hours – which is sufficient comment upon the probable accuracy of either value. Bianchini obtained a value of 24 days 7 hours 54 minutes; Schröter, 23 hours 28 minutes; Trouvelot, in 1892, 23 hours 49 minutes 28 seconds. Actually, none of these estimates were of any real value, and it is rather surprising that they should have been made to the nearest second – or, in the case of Leo Brenner in 1896, to the nearest thousandth of a second! It is rather like measuring the age of the Earth to the nearest minute.

Lowell, from a study of his 'steel engravings', supported a suggestion by Schiaparelli that Venus, like Mercury, kept the same face permanently towards the Sun, and that the rotation period

[1] There may be a clue here to the puzzle of why some observers show streaky markings which are totally invisible to others using similar telescopes. In the autumn of 1953, an interesting but very rough experiment was carried out by four planetary observers – R. M. Baum, J. B. Hutchings, C. D. Reid and myself. Using a spectroscope, we found that Baum's eyes were unusually sensitive to light of short wavelength, Hutchings' and Reid's more normal, and my own rather insensitive. The significance of this is that Baum sees the streaky cloudlike features clearly, and Hutchings and Reid with difficulty, while to me they are invisible. Possibly, therefore, the broader linear features result from misinterpretation of much vaguer streaks high in the Cytherean atmosphere – in which case only those observers whose eyes are very sensitive to short wavelengths can hope to glimpse them in the ordinary way. However, it will be necessary to make more accurate experiments before coming to any definite conclusions.

was thus 225 days. Schiaparelli had been right in the case of Mercury, but he was wrong about Venus. This has been proved by direct measurements of the temperature of the night side, which turns out to be much warmer than would be the case if it never received any direct sunlight at all.

The amount of heat sent to us by Venus is, of course, very small; but even so, it can be measured by a special instrument known as a thermocouple. If we take two wires made of different metals, and solder their ends together to make a complete circuit, an electric current will be set up if the joins are at different temperatures. A current can, therefore, be produced by warming one of the joins and keeping the other at a constant temperature; and even the tiny current produced by the heat of Venus can be measured.

Pettit and Nicholson, at Mount Wilson, used the great 100-inch reflector there to concentrate the light (and therefore heat) of Venus, and then measured the electric current produced. After additional corrections had been made, they were able to give reliable values for the surface temperatures – or, more accurately, the temperatures of the upper clouds. Their results were of the greatest interest. The sunlit side turned out to be at a temperature of about 130° F., while the night side was not particularly cold – in the region of – 10° F. This at once disposes of Lowell's idea of an equal day and year. Even allowing for heat being carried round to the dark side by Venus' atmosphere, the temperature under such conditions would be bitterly chill, as is the case on Mercury.

But if we reject the very long rotation, we can also reject Trouvelot's 23-hour period, as it can be proved that the rotation of Venus is much slower than our own. As Venus spins on its axis, one limb must approach us, while the other recedes; and if this motion were at all rapid, it could be detected by the spectroscope. Up to now it has not come to light, and we can thus be certain that the speed of spin is slow. Günter Roth, a leading German observer, investigated the problem in 1953 and arrived at a value of about 15 days; others consider about 30 days to be more probable. It is unlikely that this particular problem will be solved until we have the chance to examine the planet at close quarters.

At all events, the Cytherean calendar will be pleasingly straightforward. There will be only seven or eight days in every year.

It is evident that all our efforts to probe the mysteries of Venus are checkmated by the thick, hazy atmosphere, which forms a mantle that we are unable to pierce. What can we find out about the atmosphere itself?

Its existence has been known for a long time, and its thickness

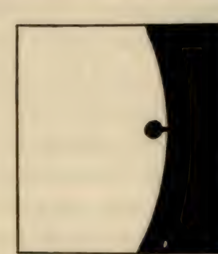


Fig. 8. The 'Black Drop'

was a source of irritation to astronomers some eighty years ago, in 1874 and 1882, when efforts were being made to measure the distance of the Sun. At first sight it would not seem as though Venus could be of much help in this connection; but Venus, like Mercury, occasionally passes in transit across the solar disk, and these transits could be turned to good account.

In Fig. 9, which is not to scale, the Sun, the Earth and Venus

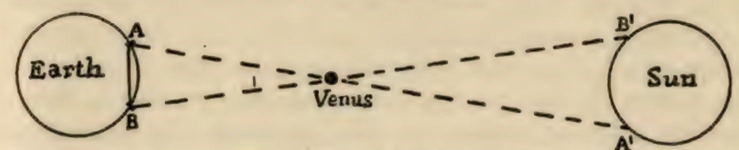


Fig. 9. Transit of Venus

are shown, with Venus directly between the Sun and Earth and therefore in transit. From a position A on the Earth, Venus will be seen in position A^1 against the Sun; from position B, at B^1. If simultaneous observations are made from A and B, and the distance between A and B is known, the entire diagram can be drawn to scale and the distance of the Sun worked out.

In practice the procedure adopted was rather different. The

result was obtained by calculation, not by scale drawing; and instead of measuring the exact position of Venus it was found better merely to time the moment at which the planet passed fully on to the solar disk. This provided all the necessary data.

Unfortunately, transits of Venus are most infrequent. They appear in pairs, each pair separated from the next by over a century. The first two transits to be scientifically observed were those of 1761 and 1769, and it was then that a French astronomer, Legentil, met with a strange series of misfortunes which must surely be unparalleled in all scientific history.

Legentil set out in 1760, bound for India, where the 1761 transit was expected to be favourably visible. Unluckily for him the Seven Years' War was still raging, and he did not arrive until after the transit was over. Rather than risk a second delay, he decided to remain where he was for the next eight years, and wait for the transit of 1769. Fate could hardly have been more unkind. Shortly before and shortly after the vital hours, the sky was brilliantly clear; but the transit itself was completely hidden by clouds, and as it was rather too long for Legentil to wait until the next transit (that of 1874) he packed up what belongings he could, and set off for home. Twice he was shipwrecked, and eventually reached Paris to learn that he had been presumed dead, so that his heirs were preparing to divide his property. Actually, he lived for another twenty years, and did not die until 1792.

The 1874 and 1882 transits were well observed, but the accuracy of the whole method was ruined by Venus' inconvenient atmosphere, which caused an effect known as the 'black drop'. As the planet drew in front of the Sun, it seemed to draw a strip of blackness after it; and when this blackness disappeared, the planet was found to be well on the disk. It was therefore impossible to get an accurate estimate of the moment when the transit really started. The effect is purely optical, but it was serious enough to wreck the method completely. Fortunately there are now other and better ways of determining the distance of the Sun, and the next transit, that of 2004, will not be regarded as of much importance.

Another atmospheric phenomenon which intrigued the early observers is that known as the Ashen Light – the faint luminosity of the so-called 'dark' hemisphere of Venus against the brilliant crescent. This has been seen by many observers, and its existence cannot be doubted, although so far it remains unexplained.

Something similar is seen in the case of the Moon, popularly known as "the Old Moon in the New Moon's arms", and was correctly explained by Leonardo da Vinci as being due to the brilliant earth-light upon the lunar surface. Full moonlight can be brilliant upon the Earth, as we know well; to an observer on the Moon, the Earth would appear as a glorious, shining globe, flooding the rocks with radiance powerful enough to make them glow. However, no such explanation can account for the Ashen Light of moonless Venus, and some sort of atmospheric phenomenon must be responsible.

The fact that the atmosphere is so deep means that the cusps will often appear prolonged in narrow lines of light, and indeed the bright line can sometimes be followed right round the dark hemisphere, forming a ring. But actual luminosity of the dark side is another matter. Schröter and other last-century observers were familiar with it, and Gruithuisen, one of the astronomers of the Observatory of Munich, thought that it was due to the glow from vast forest fires lighted by the inhabitants of Venus during religious festivals! There are, perhaps, some objections to this theory, and a saner suggestion is that the Light is caused by strong auroræ in Venus' upper atmosphere.

Terrestrial auroræ, or Polar Lights, are high-level atmospheric glows caused by streams of electrified particles sent out by the Sun, and there is no reason why similar effects should not occur on Venus; in fact, they may well be much stronger, as the distance from the Sun is less. Very probably the Ashen Light is due to this cause. It is certainly not a mere contrast effect, as has been suggested.

During the spring of 1953 I recorded that the Ashen Light was particularly conspicuous; and on April 1 a most interesting observation was made by Clyde Tombaugh and C. C. Post in America. Using a red filter, they saw that the 'dark' regions were shining with a reddish glow against the narrow, brilliant crescent. This, too, may have been due to Cytherean auroræ.

The telescope is not the only powerful weapon in the hands of the modern astronomer. Almost equally valuable is the spectro-

scope, which splits up the light from distant bodies and tells us what materials are responsible for it. In this way we have found out something about the gases which make up the atmosphere of Venus, and the results are both surprising and disappointing. Where we had hoped to find life-giving oxygen and precious water-vapour, we actually find – nothing but smothering, choking carbon dioxide.

Carbon dioxide is not poisonous, but neither is it breathable, and it also tends to act as a 'blanket', shutting in heat. The air of the Earth contains very little of it, largely because plants remove it and replace it by oxygen; the vast quantities of carbon dioxide on Venus seem, at first sight, to show that vegetation has never obtained a foothold there. Second thoughts, however, lead us to be more cautious.

For one thing, only the uppermost part of the Cytherean atmosphere is available for spectroscopic examination, and we must remember the old saying that we "must never judge a sausage by its overcoat". Even in our own upper air there is very little oxygen or water-vapour, and we have no knowledge at all of conditions beneath the clouds of Venus; nor do we know the exact nature of the clouds themselves. Spectroscopic observations have shown that the whole cloud layer is in violent motion. Dr. H. Suess has suggested that the clouds are made up of salts such as sodium chloride and magnesium chloride, produced by the evaporation of former oceans; R. Wildt believes that they are made up of 'formaldehyde', a compound of carbon, hydrogen and oxygen. But these are only theories, unsupported by any observational evidence, and the plain truth is that we simply do not know. The Goddess of Love is disinclined to reveal her secrets.

Handicapped as we are, we can only guess at what the surface of Venus may be like; and we have two possible pictures before us.

One is that of a dusty, lifeless planet, a universal desert, with screaming gales tearing through the dense, choking atmosphere, levelling everything in their path; a temperature above that of boiling water, and the whole scene shrouded by a smothering, fuming carbon dioxide mantle through which even the fierce rays of the Sun cannot penetrate.

The other picture is much more attractive. Here we have a moist, humid world, protected from the intense sunlight by the shielding clouds, so that the surface temperature is pleasant; a world of tropical vegetation, with oceans and islands, and perhaps primitive forms of life – similar to those which vanished from the Earth in the far-off days when the great coal deposits were being laid down; insects, fishes such as the coelacanth, and even great reptiles crawling and rustling through the dense, warm undergrowth.

Even though the first picture seems the more likely, we cannot rule out the second; and as Venus is the nearest of our planetary neighbours, it is not unreasonable to hope that we may find out before many centuries are past. As the escape velocity there is high, and taking-off on a return journey much more difficult than from Mars or the Moon, it will probably be prudent to make a large number of 'round trips' before attempting an actual landing, and inspection from close range should enable us to find out whether or not Venus is a desert world.

One thing is almost certain. If there is life on Venus it will be of low type; intelligent beings do not exist there. When the first men land upon the surface, and look out upon the dense clouds swirling through the air that no humans may breathe, they need have no fear of being attacked by unfriendly beings living upon our sister world.

CHAPTER 6

The Earth

The third member of the Sun's family holds a special position in our eyes. This is natural; the Earth is our world, our home, and at first we find it difficult to realize that it is merely an ordinary planet, in no way remarkable.

The ancients found such an idea quite beyond their grasp, and up to less than five hundred years ago it was commonly believed that the Earth was the centre of the universe. It was also thought that the Earth was flat, and there are still a few people who hold to this opinion, despite the curvature of the surface shown unmistakably in photographs taken from high-altitude rockets.[1]

However, Pythagoras, some 2,500 years ago, knew that the Earth is a globe; another Greek scientist, Heraclitus of Pontus, is credited with the discovery that the heavens appear to circle the Earth once a day simply because the Earth itself is spinning on its axis; while Eratosthenes, about B.C. 230, made a remarkably accurate estimate of the Earth's size.

Actually, the Earth is not perfectly spherical. It is turning on its axis, and so centrifugal force is most powerful at the equator; consequently there is a definite bulge in the equatorial region, and the Earth has taken up a shape known technically as an 'oblate spheroid' – the shape of a very slightly flattened orange. However, the difference between the polar and equatorial diameters amounts to only 26 miles, which is not much when we remember that the mean diameter is about 7,900 miles. If we took a billiard ball and flattened it by an equivalent amount, the ball would still be usable for play. The less dense and quicker-spinning giant planets, particularly Jupiter and Saturn, show the

[1] Other shapes have also been suggested, such as that of 'a large duck egg'. There are also a few earnest people who are convinced that the Earth is merely the inner surface of a hollow sphere. A prominent member of the British Interplanetary Society recently suggested that it would be interesting to confront a hollow-sphere enthusiast with a Flat Earthist, and let them fight it out!

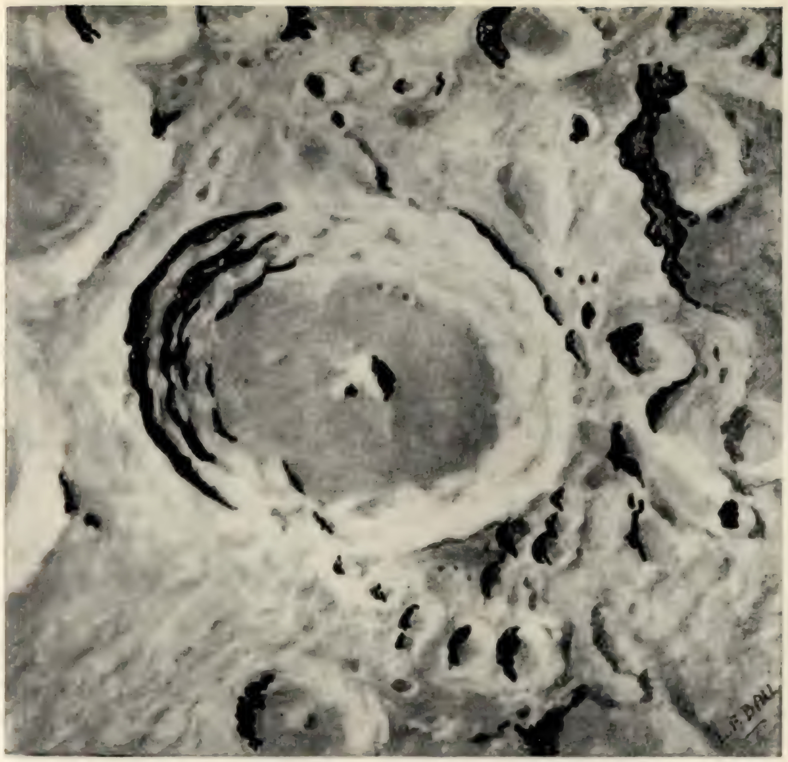


PLATE VII. Tycho (1949, Mar. 9, 23h. 30m. ×350, L. F. Ball)

PLATE VIII. Venus, showing Ashen Light (1953, Apr. 3, 18h. 30m., 3-inch O.G. ×180, R. M. Baum)

Red photograph: 1952, Apr. 22, 0h. 1m.

Blue photograph: 1952, Apr. 22, 0h. 40m.

PLATE IX. Mars, in blue and red light (photographs, Mount Wilson and Palomar Observatories).
Taken with the 200-inch Hale Reflector

effect much more clearly, and even a small telescope will show that they are obviously flattened at the poles.

The Earth, then, is a normal planet – larger than Mercury or Mars, about the same size as Venus, far smaller than the outer planets. The orbit, too, is perfectly normal. The average distance from the Sun is 93 million miles, and owing to the low eccentricity this distance does not vary by much more than a million miles either way. The orbital speed is about $18\frac{1}{2}$ miles a second – a little more near perihelion, a little less at aphelion. It is strange to reflect that in a world where high speed has become a craze, Nature has outclassed our efforts completely without most of us being aware that we are being whirled round the Sun at all.

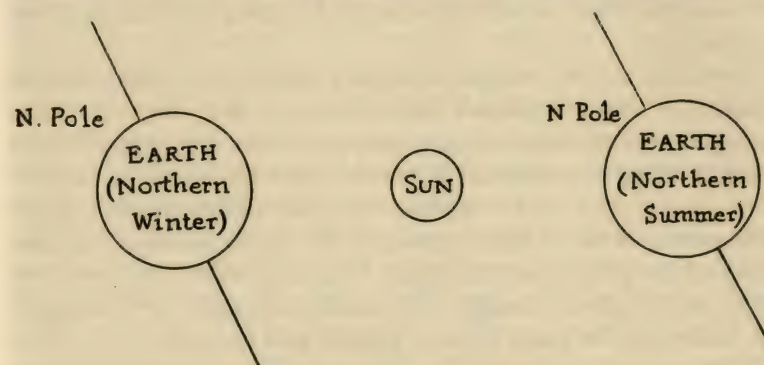


FIG. 10. The Seasons

Oddly enough, the northern summer occurs when the Earth is near aphelion, at its farthest from the Sun. This is because the axis of rotation is not perpendicular to the plane of the orbit, but inclined at an angle of $23\frac{1}{2}°$ (Fig. 10). During the northern summer, the north pole is tilted towards the Sun; six months later it is the turn of the southern hemisphere, and it is winter in the north. Because the Earth is at its closest to the Sun in the southern summer, extremes of temperature are greatest south of the equator, with hotter summers and colder winters; but the effect is not great, and is largely masked by the Earth's geographical peculiarities. The effect is much more marked upon Mars, where the axial tilt is similar but the orbit much more elliptical.

Considering that we have lived all our lives upon the Earth, we know surprisingly little about what lies beneath our feet. We can only penetrate a few miles downwards – the deepest oil-well in the world, in California, stops at some 21,000 feet – and from then on we are reduced to pure theory. We are not even sure how hot the Earth is near its centre.

Wells drilled into the ground show that the temperature rises about one degree Fahrenheit for every fifty feet down, though the exact value varies for different localities. If this rate of increase continued to the Earth's core, the temperature there would be some 400,000° F. – which seems most unlikely. Hence, the temperature gradient cannot remain constant. It is now generally believed that the central temperature is only a few thousands of degrees.

Even this is hot enough to liquefy most rocks under normal conditions, but conditions deep down in the Earth are not 'normal'. The pressure of the overlying layers is tremendous. At a depth of only 25 miles, for instance, the estimated pressure is some 10,000 tons to the square foot, and although rock under such pressures would still technically be 'liquid', it would assume many of the properties of a solid. Near the centre, the pressures must be fabulous – though still small compared to those near the centres of the giant planets, Jupiter and Saturn.

There is only one respect in which the Earth seems to be unusual in the planetary system. It is particularly dense. It weighs, on an average, 5½ times as much as an equal volume of water, whereas Venus has a density of only about 5 on the same scale, and the other planets are even less substantial. (Saturn's mean density is actually less than that of water.) It is no easy matter to determine the density of the Earth, but there seems little doubt that the inside of our world is not only hot but also heavy. In fact, the core may consist largely of iron.

Studies of earthquake waves, produced by the sudden slipping of the Earth's crustal rocks, and also of volcanic eruptions, which prove at least that there is a good deal of internal heat left, lead us to the conclusion that the Earth possesses a core made up of iron or nickel-iron with a diameter of perhaps 4,000 miles, overlaid by a layer of stony material which is in turn overlaid by a layer of rock called peridotite. The actual crust of the Earth, which feels so solid to us, turns out to be alarmingly thin, no thicker relatively than the shell of an egg; it extends down to about forty miles, and is made up largely of granite and other volcanic rocks.

If the Earth is made up in this way, it is only reasonable to assume that the remaining small planets – Mercury, Venus and Mars, as well as the Moon – are built upon a similar pattern, though their smaller mean densities probably indicate a much smaller liquid iron core.

One of the most interesting things about the Earth is its magnetism. Everyone is familiar with the ordinary pocket compass; but although we have come to accept the fact that the needle points to the north magnetic pole, we still do not know precisely why. In fact, we are not even sure just what the magnetic pole is. Magnetism is bound up with the Earth's interior. Iron, which is probably the main constituent of the liquid core, is strongly magnetic; and the variations in strength of the Earth's magnetic field, and also the wanderings of the magnetic pole, seem to be linked with disturbances in the inner core.

It is not yet known whether other planets have their own magnetic poles. On the liquid core theory, the strength of the magnetic field must depend largely upon the size of the core; smaller planets such as Mercury and Mars, more advanced in their life-histories and presumably with smaller and less turbulent cores, may thus have weaker fields. Ordinary compasses may be of little use to the first Mercurian or Martian explorers.

Turning now to the Earth's surface, we are – literally – on firm ground. The chief peculiarity, compared to other planetary surfaces, is the presence of large sheets of water; so far as we know, our seas and oceans are unique in the Solar System. The only other planets with a temperature at which liquid water could exist are Venus and Mars. We know so little about Venus that we cannot rule out the possibility of oceans, but there are certainly no extensive water-surfaces on Mars.

The tides in our oceans, so important to shipping, are due mainly to the pull of the Moon,[1] which does its best to heap up the water in a bulge underneath it, causing a corresponding

[1] For a more detailed explanation of the tides, see my *Guide to the Moon*, Chapter 14.

water-bulge on the far side of the Earth. As the Earth rotates on its axis, the water-heap does not rotate with it, but tries to remain underneath the Moon. The result is that the heaps pass right round the Earth once a day; and since there are two heaps, each point experiences two high tides. In practice, there are many complications, but the main theory is simple enough. The Sun also has a tide-raising effect, and when the Sun and Moon are pulling in the same direction (i.e. at New and Full Moon) the tides are exceptionally strong.

These tidal effects would not be at all similar for Mars or Venus, even if large sheets of water existed there. The solar tides on Venus would be more powerful than on the Earth, but still inferior to our lunar tides; and the two dwarf attendants of Mars would be quite unable to produce any appreciable tides at all, which, coupled with the Red Planet's greater distance from the Sun, would make the Martian seas still and sluggish.

One of the most interesting things about the Earth is its atmospheric mantle. Just as fish live at the bottom of an ocean of water, so we live at the bottom of an ocean of air; and the pressure of the overlying atmosphere is considerable. After all, the ordinary barometer, so familiar to all of us, is merely an instrument for registering changes in atmospheric pressure. Removal of this pressure would have most unpleasant consequences for us, just as a deep-sea fish swells and dies when it is swept to the surface of the ocean; and this is an excellent reason why efficient space-suits will always be necessary upon airless worlds, quite apart from different temperature conditions and exposure to lethal radiations from the Sun.

We know that the velocity of escape from the Earth is seven miles a second. Air is made up of molecules, which are aggregations of atoms flying about in all directions; and if a molecule happens to reach escape velocity, and is moving directly away from the Earth, it may escape into space. This is why small worlds with feeble gravitational pulls, such as Mercury and the Moon, have been unable to retain appreciable atmospheres. Even on Mars, which has an escape velocity of three miles a second, the air is thin.

It seems, however, that the Earth ought to be capable of retaining its air indefinitely; even hydrogen, lightest and quickest-

moving of all gases, should be unable to get away. However, the free hydrogen in the terrestrial atmosphere amounts to something like 0·01 per cent. in volume; two much heavier gases, nitrogen (78 per cent.) and oxygen (21 per cent.) make up between them 99 per cent. of the air – the remaining 1 per cent. being composed of argon and smaller quantities of carbon dioxide, hydrogen, water vapour, and rare gases such as neon. Hydrogen is by far the most abundant element in the universe; what has happened to all the hydrogen that must originally have been present in the air-mantle? Some of it has combined with oxygen to form water, and some has combined with the surface materials; but even so, there is a vast amount of hydrogen unaccounted for.

In the early days of its separate existence, the Earth must have been hot. Increase of temperature means an increase in the speed of molecules, and it seems that in its young, hot days the Earth lost not only most of its hydrogen, but also all the other gases originally present in the atmospheric mantle. The present atmosphere evolved mainly because volcanic action released a tremendous volume of gas from the Earth's interior.

Consequently, the Earth's atmosphere is of unusual composition. No other planet seems to possess an air-mantle containing much free oxygen. So far as we are concerned, oxygen is the life-giving gas; the nitrogen merely acts as a diluent, and though (needless to say) it is completely harmless it is of no actual use to us. It is probably true to say that we owe our existence to the presence of plants, which, by the process known as 'photosynthesis', remove carbon dioxide from the atmosphere and replace it with oxygen.

The great quantity of carbon dioxide in the atmosphere of Venus, coupled with the apparent absence of free oxygen, has been held to prove that vegetation is absent from the Cytherean surface – though we must remember that we can only examine the uppermost clouds, and it is certainly unwise to make too many speculations about conditions lower down. There is not much oxygen on Mars, and Jupiter and Saturn, with their high escape velocities, have atmospheres made up largely of hydrogen compounds – because these massive worlds were able to hold on to their original atmospheres without difficulty. It is almost cer-

tain that beings with lungs such as ours would be unable to breathe the atmospheres of any of our neighbour planets.

The terrestrial atmosphere is densest at or below sea-level; and as we ascend, the air-density falls off quickly. If we make a scale model of the Earth-Moon system, and reduce the distance between the two bodies to one mile, the ring of atmosphere round the Earth will be less than two inches deep. This is not very much; but even so, we would not be able to breathe it above the first tenth of an inch. Hillary and Tensing, on the summit of Everest, would have died without their oxygen masks, and every wartime flyer knows that it is impossible to go up much higher than three miles without breathing equipment. The lowest part of the ocean of air, that in which we spend all our lives, is known as the troposphere; it extends upwards for about seven miles, and this is also the higher limit for ordinary clouds.

Above the troposphere lies the stratosphere, and this marks the limit, so far, of actual travel into the air. In 1935 Captain Stevens, in his balloon 'Explorer II', reached an altitude of about 14 miles, but even so he was well below the ozone layer which cuts off the harmful ultra-violet radiations emitted by the Sun. The ozone layer lies about 20 miles up, and well above this, in the 'ionosphere', many of the interesting high-altitude phenomena take place.

Meteors, for instance, seldom penetrate below a height of 50 miles or so. There is no mystery about a meteor. It is a small rocky particle, circling the Sun like a miniature planet, and if it approaches the Earth too closely it is drawn down by the terrestrial pull. It dies in a brief blaze of glory as it plunges through the upper atmosphere, causing the familiar appearance of a 'shooting-star'. Incandescence, due to friction, starts at about 120 miles above the Earth's surface, so that even at this great height the air must be of appreciable density.

At a height of about 50 miles above the Earth the air-density is about $\frac{1}{10000}$ of its surface value. This is also the value of the maximum possible density of the atmosphere of the Moon; and it is therefore quite possible that shooting-stars blaze in the tenuous lunar air. Indeed, lunar meteors have recently been suspected by a number of American observers.

Nearly all meteors are very minute – mere grains of cosmic

dust. One in several millions is larger, and penetrates deeper into the atmosphere before being burned up; very occasional giants survive the complete drop, falling to the ground with a scream and a roar. One, found by Peary in Greenland, weighs 36 tons, while the tremendous object which hit Siberia in 1908 is estimated to have had a diameter of several hundred yards – at all events, it blew down pine-trees twenty miles away from the spot where it landed.

Sixty miles up is the lower limit for the brilliant displays of auroræ, or Polar Lights, caused by electrified particles sent out by the Sun. Auroræ are best seen in high latitudes, as the particles are drawn towards the magnetic poles of the Earth (the geographical poles have nothing to do with it), but brilliant displays are sometimes more widespread. I well remember the aurora of 1938 January 26, when, from East Grinstead in Sussex, the whole sky seemed to be on fire, and I thought at first that searchlights were responsible.

As we continue to ascend the air-density, and hence resistance, continues to fall off. Meteors do not become incandescent above 120 miles, and above 150 miles there is so little air left that the resistance becomes negligible. This is the region of the 'exosphere', and our rockets have reached it; the first of all successful 'step-rockets', fired from the American research station at White Sands in 1949, climbed almost out of the terrestrial atmosphere, and thus became man's first messenger into interplanetary space.

All that we know about the Earth tells us that it is a normal planet, quite undistinguished in the Sun's family. True, it is unusually dense; it has an unusual atmosphere; and it has a great deal of water – but the atmosphere of Venus is just as odd in its own way, while Mars must have at least some water on its surface. Also, the Earth has life; but even in this respect it may not be unique. We have no proof that other intelligent beings exist in the Solar System, but it is almost certain that there is plenty of vegetation on Mars, and possibly there are life-forms on other worlds quite alien to our understanding.

From Mercury, the Earth would appear as a bright point, attended by a smaller one (the Moon); but an observer on Venus, if he could penetrate his cloud-laden skies, would see the Earth as a spendid object – even the Moon would appear as brilliant as

Venus does to us. To a Martian, the Earth would be an inferior planet, showing lunar-type phases; from Jupiter, our world would be hard to see at all, and from the outer giant planets it would be quite invisible.

If we want to see the Earth-Moon system in its full glory, let us go not to the Moon itself, but to the tiny minor planet Hermes, a miniature world scarcely more than a mile in diameter. At its close approach of 1938, Hermes passed by at a distance of only 400,000 miles; if we could have seen the Earth from it then, we would have been rewarded with a magnificent spectacle – a shining, blue-green world, crossed by whitish cloudy streams and patches, with snowy poles and gleaming oceans, and attended by a smaller planet with a rough, volcano-scarred surface.

Our Hermian astronomer, if he could have existed, might well have envied Earthmen their fertile planet. Our world would indeed be a pleasant place were it peopled by a race with more advanced ideas of how to live in harmony.

CHAPTER 7

The Moon

To us, the Moon appears as a splendid object in the sky. It is not surprising that the early peoples worshipped it as a god; in fact, moon-worship in England continued up to and beyond the time of King Alfred, and in Central Africa and Brazil it is not quite dead even yet. However, we now know that astronomically the Moon is a very insignificant body. It has been relegated to the status of a mere 'satellite' or attendant of the Earth, and is thus one of the junior members of the Solar System.

The only reason for the Moon's apparent brilliance is that it is comparatively close to us. It revolves round the Earth at a mean distance of about a quarter of a million miles; Venus, nearest of the major planets, is always at least a hundred times as remote. If we return to our original scale model, with the Sun a 600-foot globe and the Earth a $5\frac{1}{2}$-foot globe over 12 miles off, the Moon will be reduced to a ball 18 inches in diameter, circling the Earth at an average distance of only 166 feet.

Yet it is not correct to regard the Moon as nothing more than an ordinary satellite. It is too large for that. It is 2,160 miles in diameter, so that it would just about stretch across the Atlantic Ocean; in other words, it has a quarter the diameter of its primary planet, the Earth. Five of the satellites of the giant planets (Callisto, Ganymede and Io in Jupiter's system, Titan in Saturn's, and Triton in Neptune's) are actually larger than the Moon – but they are very small indeed compared with their vast primaries. Titan, which is 3,500 miles across, far bigger than the Moon or Mercury and not a great deal smaller than Mars, has only $\frac{1}{20}$ of Saturn's diameter and $\frac{1}{4700}$ of its mass, whereas the Moon has one-quarter of the Earth's diameter and $\frac{1}{81}$ of its mass. On the whole, it is better to regard the Earth-Moon system as a double planet rather than as a planet and a satellite.

Whichever theory of the Solar System we adopt, it seems un-

likely that the Moon ever formed part of the Earth, as was believed until quite recently. Professor W. H. Pickering, a celebrated American astronomer of the present century, was of the opinion that the Moon broke away from the Earth and left a great, rounded scar, now filled by the waters of the Pacific Ocean; but it is now thought more probable that the Moon was always a separate world, either formed close to the Earth or captured by it when comparatively young.

We can, at least, be sure that the Moon was once much closer to the Earth than it is now. In those remote times the two worlds must have raised immense tides upon each other; the smaller and less massive Moon was the more affected, and was gradually forced into the state of keeping one face permanently towards the Earth, just as Mercury does with respect to the Sun. The lunar 'day' is thus equal to the terrestrial 'month', $27\frac{1}{3}$ days, and to an observer on the Moon's surface the Sun would appear to remain above the horizon for a fortnight at a time.

In spite of the fact that the Moon's axial rotation is equal to its period of revolution round the Earth, we can actually examine more than half of the total surface, for the same reason that the Sun appears to rise and set in the twilight zone of Mercury. The rate of axial spin is constant; the orbital velocity is not constant—because the Moon travels round the Earth in an ellipse, not in a circle, and moves fastest when closest to us.[1] We can thus see a little way round alternate edges of the Moon. Also, the lunar orbit is tilted with reference to ours, so that the Moon is sometimes north and sometimes south of the mean plane, enabling us to see some way beyond alternate poles. These minor shifts, known as 'librations', allow us to examine four-sevenths of the total surface. The remaining three-sevenths of the Moon is permanently hidden from our inquiring eyes, but there is no reason to think that it is radically different from the part which we can see.

Everyone is familiar with the 'phases' of the Moon, and the ancient peoples accounted for them in curious ways. The Slavs,

[1] It is not entirely correct to say that "the Moon turns round the Earth". More properly, the Earth and Moon revolve round their common centre of gravity, just as the two bells of a dumb-bell revolve when twisted by their connecting bar. However, the Earth is so much more massive than the Moon that this centre of gravity, or 'barycentre', lies within the Earth's globe.

for instance, believed that the Moon, King of Night and husband of the Sun, faithlessly loved the Morning Star, wherefore "he was cloven through in punishment, as we see him in the sky". Actually, the phases are due to the fact that the Moon, like the planets, has no light of its own; it relies wholly upon reflected sunlight, and the 'night' hemisphere is non-luminous. In Fig. 11, S represents the Sun, E the Earth, and M1 to M4 the Moon in different positions in its orbit. When the Moon is at M1 the night side is turned towards us, and so the Moon is invisible; this, and not the slender evening crescent, is the true New Moon. At M2,

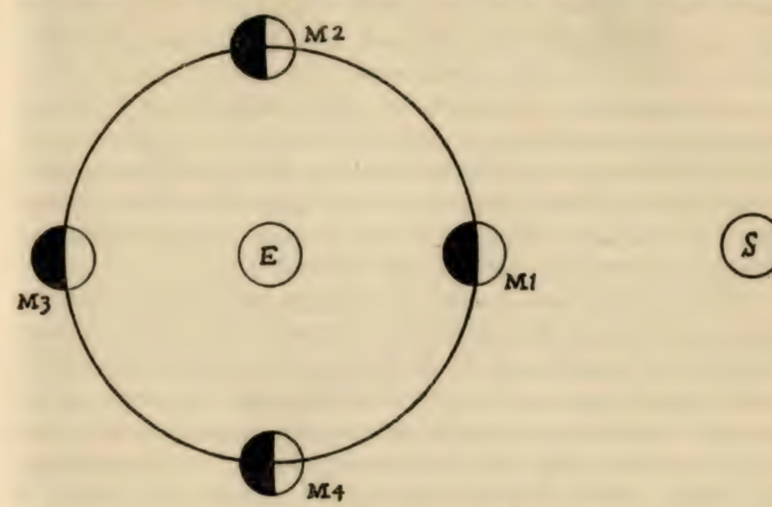


FIG. 11. Phases of the Moon

half the day hemisphere is presented to us; at M3, all of it (Full Moon); and at M4, half again, after which the Moon seems to draw back towards the Sun in the sky; and the crescent narrows until it vanishes and the Moon is new once more.

The Sun has a diameter 400 times greater than that of the Moon, but it is also about 400 times more distant, so that to our eyes the two look about the same size. When the Moon passes directly between us and the Sun, therefore, it causes a 'solar eclipse', and blots out the Sun's brilliant disk. This does not happen at every New Moon, since the Moon's orbit is tilted; total solar eclipses are rare, and the next one visible in Great Britain

will not occur until 1999 (though the eclipse of June 1954 was just total in the outer islands off North Scotland). This is unfortunate, for a total solar eclipse is a magnificent spectacle, perhaps unequalled in Nature. The dark night-side of the Moon appears like a dark pool, while round it the glorious outer atmosphere of the Sun flashes into view, and the pearly 'corona' sends its streamers across the dark, star-studded heavens.

Eclipses of the Moon are seen far more frequently than those of the Sun,[1] but are due to a very different cause. Like all opaque bodies, the Earth casts a shadow. If the Full Moon appears to pass directly behind the Earth with respect to the Sun, so that the Sun, Earth and Moon are in a straight line with the Earth in the middle, the Moon passes into the shadow of our globe. As it has no light of its own, we might expect it to disappear completely; but in practice the Earth's ring of atmosphere bends some light-rays on to the lunar surface, and so the Moon appears a dim, coppery colour. The next total eclipses of the Moon favourably visible in Great Britain will take place on 1956 November 18, 1963 July 6, and 1964 June 25 and December 19.

Although the Moon is easily our nearest neighbour in space, it is not in the least like the Earth. Instead of our oceans, forests, icefields and prairies, all we find there are rough, broken rocks. Lofty mountains tower into the black sky, and the whole surface is pitted with walled, circular depressions, ranging in size from tiny formations only a few feet across to vast plains large enough to contain several English counties put together. No breath of wind blows across the surface – there is almost no air; the silence is profound, and the whole Moon seems to sleep.

Even with the unaided eye, dark patches can be seen on the lunar surface. These make up the figure of the legendary 'Old Man', known all over the world. The early observers thought that they were seas, and named them accordingly. One great, nearly circular patch was christened the Sea of Showers; another, the Sea of Moisture; a third, the Ocean of Storms. For centuries now it has been known that there is no water anywhere on the

[1] To be accurate, lunar and solar eclipses are about equally numerous; but a solar eclipse is confined to a narrow strip across the Earth's surface, whereas a lunar eclipse, when it occurs, can be seen from an entire hemisphere. Any particular place on the Earth, therefore, will see many more lunar than solar eclipses.

Moon, but the names have never been changed, and in a way they may not be too inapt; dry as the 'seas' are now, they may once have been liquid, though it is probable that they were filled with liquid lava and not with water.

The mountains on the Moon are extremely lofty, and one or two tower to no less than 35,000 feet above the surface, appreciably higher than our own Everest. Moreover, the peaks are rougher, sharper, and probably steeper than ours. Earthly mountains have been smoothed and rounded by 'erosion', the action of wind and water; but there is no erosion upon the almost airless Moon.

But the most prominent features of the lunar surface are the walled plains or 'craters', great circular pits with sunken floors and high, mountainous ramparts. There are thousands of them. In the bright lunar uplands they crowd thickly, overlapping, ruining and distorting one another, and leaving almost no level ground, while even upon the comparatively smooth 'sea' surfaces they are frequent. Even the valleys, and the tops and slopes of mountains, are not free from them. The largest of all, a walled plain which has been named Bailly, is over 170 miles in diameter; formations 50 miles across are common, while the smaller pits are so numerous that it would be a tremendous task to count them. The most modern and reliable of all lunar maps, that of Dr. H. P. Wilkins, shows that there is hardly a square mile upon the Moon that is not disturbed by at least five or six crater-pits.

As a matter of fact, the name 'crater' is not very appropriate, since the formations are not much like terrestrial craters. The mountain walls rise to tremendous heights above the sunken interiors (one crater, Newton, is 29,000 feet deep, so that if we could drop Mount Everest inside it only the extreme top would poke out), but the walls are not high above the outer country, and it is better to think of the craters as 'rimmed holes'. Nor are the floors level. They contain mounds, pits, cracks, hillocks, smaller craters and, in many cases, lofty central mountains.

One famous crater, named 'Tycho' after a celebrated Danish astronomer of the sixteenth century, is shown in the drawing by L. F. Ball (Plate VII), and in form is typical of many others. It is over 50 miles in diameter, so that it could hold the whole of Sussex, and the walls tower to 16,000 feet above the floor, which

includes a noble, many-peaked mountain mass. Yet if we could stand inside Tycho, not far from the central peaks, the mountain walls would not be nearly so imposing as we might have expected. This is because the Moon, being so much smaller than the Earth, has a more sharply-curved surface. Even if we looked along level ground, the horizon would be only about $1\frac{1}{2}$ miles off, and in the cases of many of the largest lunar craters – such as Bailly – the bounding walls would be quite invisible to an observer sanding near the centre.

It is also a mistake to think of the craters as deep, yawning holes. They are much more like saucers than wells, and the depth is always slight compared to the diameter. This is brought out by Fig. 12, which shows a typical crater, Harpalus, in cross-section.

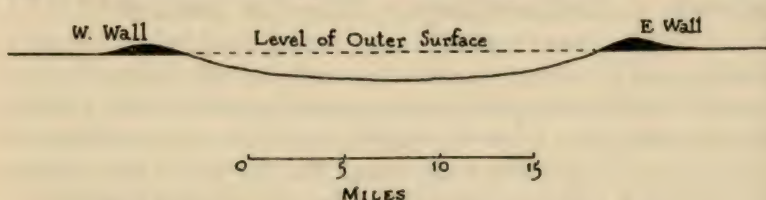


FIG. 12. Cross-section of the lunar crater Harpalus

There has been a great deal of argument as to how the lunar craters came into being, and some very strange ideas have been put forward. For instance, it has been suggested that the Moon was once covered with water, and that the craters are merely limestone formations similar to the coral atolls of the Pacific! Gruithuisen, the German astronomer who believed the Ashen Light of Venus to be due to the celebrations of local inhabitants, considered that the craters were scars made by meteors which struck the Moon when the surface was still plastic, and this idea has received a good deal of support, though as a matter of fact it is quite untenable.[1] Undoubtedly the craters were moulded by

[1] For instance, the theory would require the distribution of the craters on the Moon to be random, which is not the case. From the giant walled plains down to the tiny pits, they arrange themselves in pairs, and also in lines and chains which can only mark lines of weakness in the crust. The meteor theory puts down the tiny 'summit craters', on the exact tops of mountains, to mere chance hits; but Wilkins and I, observing with the great telescopes of Meudon and Cambridge, have recorded so many that this theory can no longer be held. The whole question is treated more fully in my *Guide to the Moon*. The meteor theory still has many supporters, but it is significant that no practical lunar observers have any use for it nowadays.

volcanic processes of some kind, though we cannot be certain as to the exact mechanism.

Many millions of years ago, before the beginnings of life upon our own Earth, the Moon must have had a thin but more or less solid crust, covering a layer of molten lava. At any weak point the lava would force its way upwards, forming a 'feed-pipe'; and before long the whole crust in the area would be lifted upwards, forming a dome. Domes of this kind are still to be seen on the Moon, and probably represent craters that never developed. In most cases, however, so much gas was expelled through the feed-pipe that the pressure below relaxed abruptly; the dome collapsed, and its surface was lowered into the hot lava below, where it melted.

Several repetitions of this process would result in a hollow, with walls high above the floor but low above the outside surface. Terraces on the inner walls, similar to those in Tycho, would also be produced; and perhaps a central elevation, built up during the dying bursts of energy from the feed-pipe. In one case, that of the formation known as Wargentin, the rising rush of lava was trapped when the escape-vent became blocked, and the crater remained full of lava; in many other cases a final phase of remelting levelled the floor, destroying any signs of a central mound.

This idea of the moulding of the lunar face may be inaccurate in many respects, but it does at least seem to account for most of the surface features. We can be certain, at any rate, that no craters of appreciable size have been formed now for many millions of years. The active life of the Moon ended long ago.

Schröter, first of the great lunar observers, detected great cracks in the Moon's surface, now known as 'clefts' or 'rills'. They are long, narrow and deep, stretching sometimes for over a hundred miles; the most prominent of them can be seen with a very small telescope. Hundreds of clefts are known, but some of them turn out to be merely chains made up of small craterlets which have run together and coalesced, with the destruction of their common walls.

In early 1954 a great deal of popular interest was aroused when it was announced that a 'bridge' had been discovered on the Moon. It is true that a natural arch does seem to exist on the border of the lava-plain known as the Sea of Crises; it was first

found by J. J. O'Neill in America and confirmed by Dr. H. P. Wilkins in England, while I have seen indications of it myself. However, it is neither prominent nor important. It had not been previously detected only because it is a minor feature in a highly mountainous region.

Perhaps the most puzzling of all lunar features are the straight, bright streaks or 'rays' which radiate from some of the craters, notably from Tycho. They cannot be seen at all under low lighting, but at Full Moon, when the whole lunar disk is illuminated, they are so prominent that they drown much of the normal detail; they pass unchecked over mountains, ridges, clefts, craters and even the mightiest walled plains, so that they must be due to some sort of surface deposit. Salt has been suggested, but it is much more likely that the rays are due to volcanic ash, ejected from the central 'feed-pipes' of Tycho and other craters in the last stage of their active lives.

To the amateur equipped with a small telescope, the Moon is probably the most fascinating of all celestial bodies, as so much detail can be seen on it. Strangely enough, however, Full Moon is the very worst time to observe, as the craters are then in full sunlight and shadows are at their minimum. All that can be seen is a dazzling, patchy surface, crossed by the brilliant rays from Tycho and a few other craters. Even the deepest walled plains appear only as blurred spots. Before or after Full, however, the sight is magnificent. Craters on or near the terminator are thrown into sharp relief by the long, tapering shadows which they cast across the surface of the Moon.

High peaks, catching the first gleams of sunshine in the lunar morning or the last in the lunar evening, may shine as starlike points from the 'night' side, apparently detached altogether from the main body of the Moon; a great crater may appear with its walls and perhaps the top of its central peak brilliantly lit, while its floor is still bathed in inky darkness. Even low-ramparted craters take on a temporary importance, and show as great indentations in the bright border. Probably the terminator of Mercury would appear similar, were we close enough to see it properly.

A noticeable peculiarity of the lunar shadows is that they are very black. There are no half-lights on the Moon. This is because

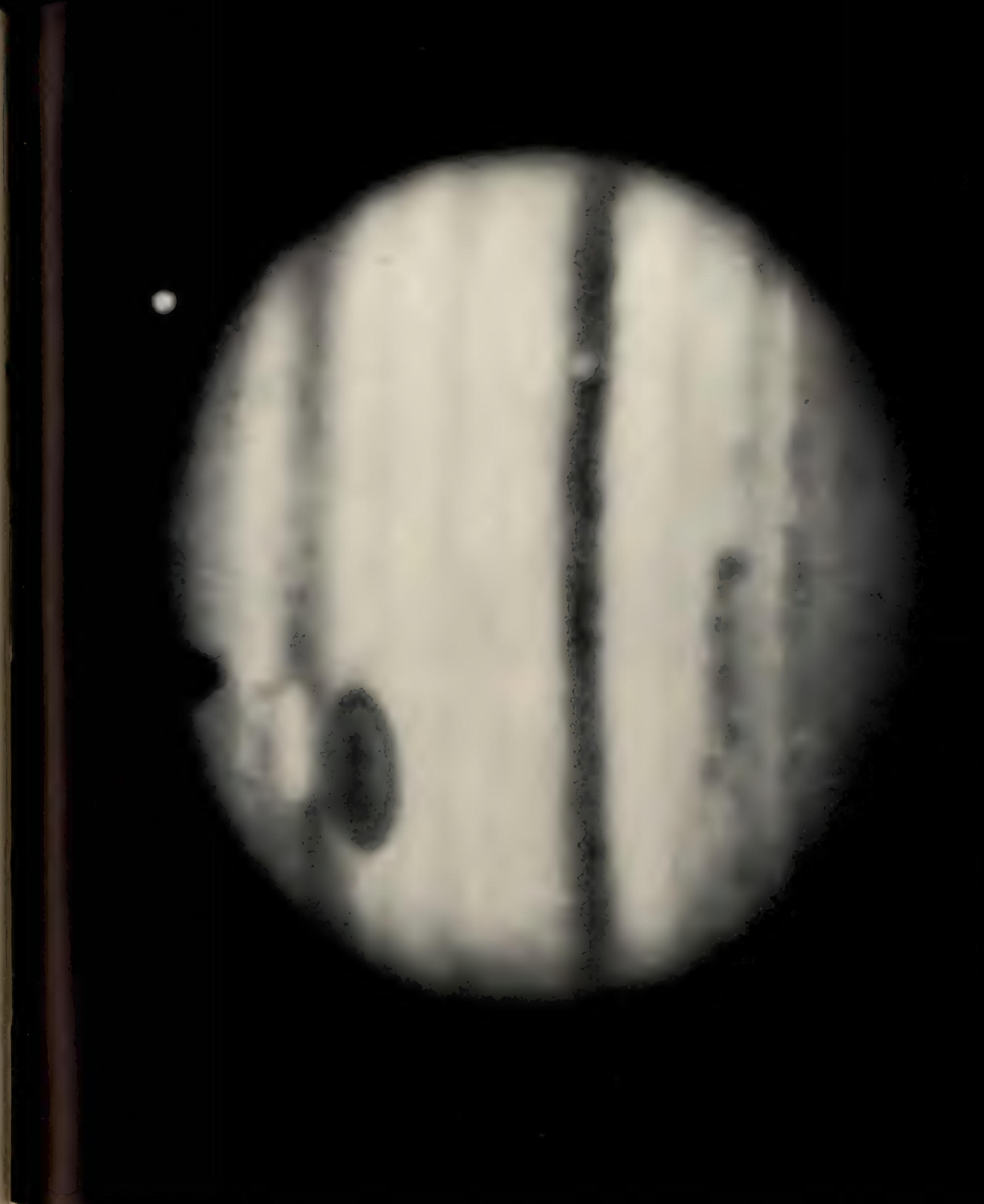


PLATE X. Jupiter, in blue light, showing the Great Red Spot. Satellite Ganymede and shadow (above) (1952, Oct. 23, 23h. 41m., photograph, Mount Wilson and Palomar Observatories). Taken with the 200-inch Hale Reflector

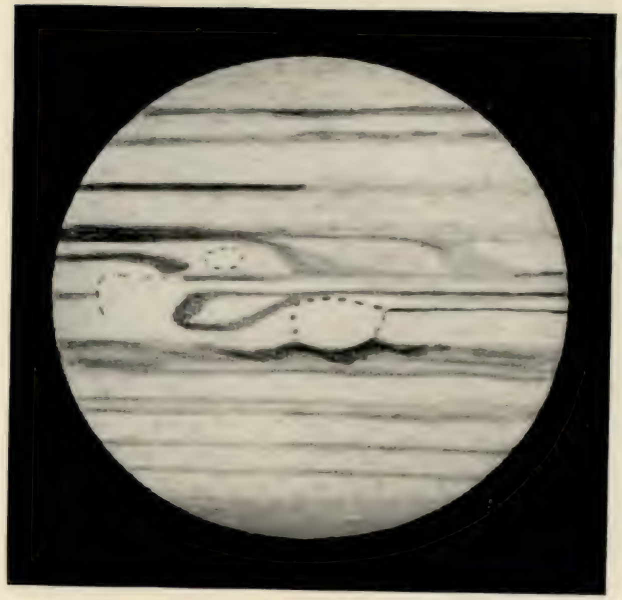


PLATE XI. Jupiter (1950, Sept. 13, $4\frac{1}{2}$-inch refl. $\times 265$, G. D. Roth)

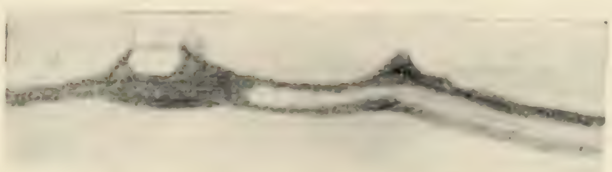


PLATE XII. Detail in Jupiter's north equatorial belt (1951, Aug. 30, 0h. 58m., $8\frac{1}{2}$-inch refl. $\times 380$, Patrick Moore)

there is almost no atmosphere; and, in fact, most of the differences between the Earth and its satellite can be traced back to the Moon's comparative airlessness.

Until fairly recently, the Moon was thought to possess no atmosphere at all. It is quite certain, of course, that there is no dense air-mantle; now and then the Moon appears to pass in front of, and 'occult', a star, and when this occurs the star seems to snap out instantaneously – whereas if the lunar limb were covered with a layer of atmosphere, the star would appear to flicker and fade for some seconds before disappearing.

However, many observers have seen things which lead them to believe that the Moon still possesses a very thin blanket of atmosphere. For instance, 'twilight' has been recorded from time to time at the horns of the crescent Moon, and the horns themselves have been seen hazy and prolonged, like those of Venus; certain craters have been observed to be filled with pale luminosity, as if containing mist; puffs of 'vapour' have been recorded; and Professor Haas and his fellow-observers in America have detected luminous streaks which may well be due to meteors flaring through the tenuous lunar atmosphere.

Moreover, a Russian astronomer, Y. N. Lipski, announced in 1949 that he had definitely detected an atmosphere with a ground density equal to $\frac{1}{10000}$ of our own – which would mean that the surface density of the Moon's atmosphere is about equal to that of the Earth at a height of fifty miles, where most terrestrial meteors burn themselves out.

Lipski's method was an indirect one, similar to that used by Dollfus to detect an atmosphere on Mercury. His results have not yet been confirmed, and in any case the lunar air cannot be at all like our own; probably it is made up mainly of carbon dioxide, a gas given off in large quantities by volcanoes, with traces of heavy rare gases such as krypton and xenon. We could not breathe it, even if it turned out to be thousands of times thicker than can be actually the case.

Another result of this virtual airlessness is that the Moon's surface becomes very hot during the lunar day but bitterly cold at night. Pettit and Nicholson, at Mount Wilson, have found the maximum temperature to be 214° F. – just above that of boiling water – while at lunar midnight it drops to −250° F., about the

temperature at which ordinary air liquefies. Truly, the Moon is an uncomfortable world. Space-travellers of the future will have to equip themselves with highly efficient insulating suits.

Heated bodies send out radiations of all kinds, including the so-called 'radio-waves', and the Moon is no exception. In 1949 two Australian investigators, Piddington and Minnett, measured the temperatures as derived from a study of these radio waves, and obtained values which did not show nearly such extremes as those found by ordinary methods. The reason for this discrepancy is clear enough. The radio waves pass almost unchecked through the Moon's outer coating, and thus give the temperature not of the actual surface but of a layer some way below the ground.

Evidently the Moon is covered with some substance that is a very poor conductor of heat. Pulverized rock and coarse dust are possibilities, but on the whole volcanic ash seems the most likely answer. It is an effective insulator, it behaves in a way which fits the observations, and it is only to be expected upon a world which shows so many signs of tremendous volcanic activity in the past.

Dr. Johann Mädler, a German astronomer who devoted a great deal of time to lunar observation between 1820 and 1840, considered that the Moon was a dead, changeless world, where nothing ever happened, and the lifeless rocks had lain motionless and unaltered for millions upon millions of years. Nowadays, a rather different view is held. It is true that surface changes are few and far between; but they do occur occasionally, and one crater, Linné, has certainly undergone a radical change in form during the past hundred years or so. The story of Linné is worth re-telling.

Up to 1843, it was drawn by all observers (including Mädler) as a deep, prominent crater in the relatively smooth area of the Sea of Serenity. The diameter was eight miles, and there was nothing else of importance anywhere near it. In 1865 another skilful German observer, Julius Schmidt, discovered that Linné no longer existed as a crater; it had disappeared, and in its place was a white spot. Schmidt, who had observed Linné both before and after its supposed change, was quite convinced that a major alteration had taken place, and indeed there seems little doubt that something – perhaps a minor 'moonquake' – caused the

walls of the old crater to cave in. Today, Linné consists of a deep, minute crater-pit standing on the crest of a dome and surrounded by a whitish deposit.

Other changes have been recorded from time to time; and although the details which undergo modification are always very minor, it is clear that Mädler's idea of a completely dead Moon must be revised to some extent. A very limited amount of activity seems to linger on.

However, there is no doubt at all that animal life on the Moon is absolutely out of the question. No beings could possibly manage to survive under conditions of such extremes of heat and cold, coupled with a total lack of food, water, and even breathable air. Even plant life is highly problematical. It is possible that certain dark markings inside a few of the craters may be due to a very low type of lichen or moss which manages to exist upon gas exuded from cracks in the ground, but there is no proof of it. To all intents and purposes, the Moon is lifeless.

In the days of crater-building, the Moon must have been a veritable inferno, with giant volcanoes roaring into the sky and lurid lights flaming everywhere as the surface was torn and rent by mighty eruptions. But all that belongs to the remote past. Today, a deathly silence broods over the ashy rocks; all we shall find, when we land there, is a landscape of ridges, hummocks and crater-pits, high mountains, and great sunken amphitheatres with raised walls.

Nor must we expect to find any evidence of former life. The Queen of Night has been barren throughout her long existence; no beings have ever crawled over her grey rocks, no footsteps have ever echoed across her plains. Within the next century, things may well be different. The greatest of all human adventures is within our grasp, and the Moon's awakening will be left to men of our own world.

CHAPTER 8

Mars

Of all the members of the Sun's family, there can be little doubt that the red world Mars, first of the planets which we find beyond the orbit of the Earth, holds the greatest interest for us. Venus may be more nearly our twin with regard to size and mass, but Mars is the Earth's true brother; on the whole the two planets do not seem to be very dissimilar, and it is on Mars alone that we may possibly find life of a form not entirely alien to our own.

When at its closest, as it will be in 1956, Mars shines brilliantly down from the heavens like a blazing ruby, brighter than any other star or planet apart from Venus. Its fiery colour led

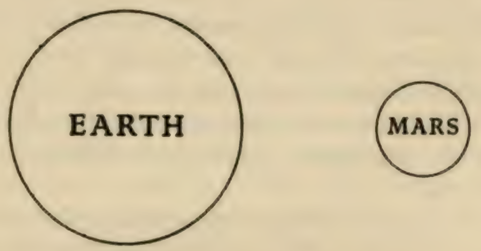


FIG. 13. Comparative sizes of the Earth and Mars

the ancients to name it after Ares or Mars, the God of War, and this is also why most story-tellers of the past have made their 'Martians' sinister, aggressive folk. We have no proof at all that any Martians exist; but if so, they may well be more advanced than us.

Mars is a comparatively small planet. It is 4,200 miles in diameter, and has little more than one-tenth of the Earth's mass, so that its great brilliancy must be due to its comparative closeness. Apart from Venus, Mars is in fact the nearest of the planets, and can approach us to within 35 million miles. Astronomically,

this is not far; but even at its closest Mars is always 140 times as distant as the Moon, so that even with our greatest telescopes we can never have a better view of Mars than we can have of the Moon with low-power binoculars. Consequently, it is not correct to say that we have a really satisfactory knowledge of conditions on the planet, though we certainly know more about Mars than we do about Mercury or Venus.

One of the things which the first Martian colonists will find unfamiliar will be the length of the year. The mean distance of Mars from the Sun is 141 million miles, and the 'year' is equal to 687 terrestrial days, so that a man who was thirty years old by Earth reckoning would be only sixteen according to the Martian calendar. On the other hand, the 'day' on Mars is about the same length as our own – a mere forty minutes longer; the exact value is 24 hours 37 minutes 22·6 seconds, and this is certainly accurate to within a tenth of a second. The hard, well-defined markings on the disk make the axial rotation period easy to determine. So far as we know, Mars and the Earth are the only planets with rotations in the order of 24 hours; Mercury and Venus spin more slowly, the giant planets much more rapidly.

Nor would the Martian seasons seem strange to us, apart from their length. The axis of Mars is tilted at an angle of $25°$ to its orbit, as against our $23\frac{1}{2}°$, so that conditions are very similar. In the northern hemisphere of Mars, winter lasts for 160 days, spring 199, summer 182 and autumn 146. These figures are slightly different for the southern hemisphere, where the winters are longer and colder and the summers shorter and hotter – because Mars' orbit is more eccentric than ours, and the southern summer occurs near perihelion, when the planet is at its closest to the Sun and moving most rapidly in its path.

The actual temperature of the Martian surface has been measured with considerable accuracy, and conditions prove to be very reasonable. The old idea of Mars as a frozen, bitterly chill world is very wide of the mark. In the tropics, the summer temperature may rise to as much as $70°$ F.; and although the nights and winters are very cool judged by our standards, Dr. de Vaucouleurs, a leading French planetary observer, has justly stated that the general temperature of Mars "is not very different from that of the Earth, and only a little more rigorous on the average".

Moreover, there have been recent suspicions that the calculated and observed temperatures are too low. We do not know yet quite what effect the Martian atmosphere has; it may be a better blanket than we have thought, and quite possibly the first explorers to land there will have a pleasant surprise in this respect.

However, one thing will seem strange to them; they will weigh very little. Mars is not only smaller than the Earth, but considerably less dense, which probably indicates that the iron core is small. The velocity of escape is only 3 miles a second, and a man who weighed 14 stone on Earth would weigh only 5 stone on Mars. This fairy-like lightness will have disadvantages as well as advantages, but at worst it will be no more than inconvenient.

In general, then, Mars appears to be not unlike the Earth. It is smaller and cooler, but basically it is built upon the same pattern, and it is not surprising that all through the ages it has been regarded as a likely abode of intelligent life.

Unfortunately, Mars presents its own observational problems, due principally to the fact that its orbital speed – 15 miles a second on the average – is only a little less than ours, and, as is explained in Chapter 3, oppositions only occur at intervals of about 780 days. There were oppositions in 1950, 1952 and 1954, while another is due in 1956; but in 1951, 1953 and 1955 Mars was so far away, and so close to the Sun in our skies, that few useful observations of it could be made, even with large telescopes.

Another difficulty is that all oppositions are not equally favourable. This is because the orbit of Mars is decidedly elliptical. When opposition occurs with Mars at perihelion, the minimum distance from the Earth can be reduced to as little as 35 million miles, but this is increased to over 60 million miles for oppositions which take place with Mars near aphelion. The 1956 opposition will be exceptionally favourable, so that Mars will be a splendid, gleaming object in the night sky.

It can also be seen that Mars sometimes shows a slight phase, and can appear the shape of the Moon a few days before or after full. For obvious reasons, Mars never appears as a half or crescent.

One of the beauties of observing Mars is that we can actually study the solid surface in some detail. We are not reduced to occasional glimpses, as in the case of Mercury; neither are we baulked by the dense layers of cloud which prevent us from finding out much about Venus or the giant planets. Even a small telescope will show something, while a moderate instrument will reveal a reddish-ochre disk upon which are darker, blue-green patches, well shown on the two drawings by L. F. Ball (Frontispiece). These dark patches are permanent, and we can therefore draw up a map of Mars just as we can of the Earth; such a map, drawn by R. Barker, one of the most experienced of all British planetary observers, is shown in Fig. 15. The wedge-shaped marking known as the Syrtis Major is well shown both on Ball's drawing and Barker's map, and has evidently altered little since 1659, before the Restoration of King Charles II, when it was drawn by the Dutch astronomer Christian Huygens.

Originally the reddish-ochre areas were thought to be deserts, the dark patches seas. The first idea is basically correct; the second is definitely wrong, as there are no large sheets of water anywhere on Mars. On the other hand, it is natural to suppose that the bright white polar caps, well shown in all the drawings, are due to ice or snow. The Earth has snow-caps of the same type.

As a matter of fact, there was a good deal of argument before the caps were proved to be icy. It was often considered that they were due to solid carbon dioxide, though there seemed no logical reason why carbon dioxide should have accumulated there. However, Kuiper, a leading American observer, cleared the matter up in 1947. By spectroscopic observations he proved that the Martian caps show definite traces of water ice.

Despite this, it would be wrong to jump to the conclusion that the poles of Mars are coated with vast ice deposits similar to those of Greenland or Antarctica. Like the caps of the Earth, the Martian snows melt during the spring and re-form during the winter; but they melt so quickly that it seems unlikely that they can be more than a few inches thick. At its greatest extent, the ice-cap of Mars' south pole may be three thousand miles across, stretching about half-way to the equator; but six Martian months later, it may have vanished entirely. The northern cap never quite disappears, but neither is it ever so large as its southern counterpart at maximum. This is because the temperature extremes in the northern hemisphere are less violent.

Perhaps it is not strictly correct to say that the polar caps

'melt' in the spring. We are used to ice and snow turning to water when the temperature rises above freezing-point, but conditions are different on Mars; the atmospheric pressure is less, so that water boils at a much lower temperature (77° F., compared with 212° F. for the Earth). Instead of melting in the conventional way, much of the Martian snow may sublime, i.e. pass directly from the solid to the gaseous state. This may account for the whitish cloudy veils often seen above the caps.

Tikhoff, a Russian astronomer, has suggested that the caps may be due to nothing more than a layer of hoar-frost. This is possible, of course, but on the whole it seems rather unlikely. There is nothing improbable about Earth-like caps upon a world so Earth-like as Mars.

However, there can be no doubt about the thinness of the caps, and this sums up the whole problem of the Red Planet: Mars is desperately short of water. It has developed more rapidly than the Earth, and has lost more of its atmosphere, so that it is approaching old age; and if all the liquid locked up in the two caps could be released at once, the total volume would not be sufficient to fill the Great Lakes.

Despite the great reddish tracts, which are certainly desert in nature, the early observers did not realize the seriousness of the water shortage on Mars, as they were convinced that the dark areas were seas. The idea was natural enough, but there are any number of fatal objections to it. For one thing, they are far from blank – much detail can be seen in them, as is shown in R. M. Baum's chart of the Syrtis Major (Fig. 14) – and whatever the dark areas may be, they are certainly not seas.

It is possible, however, that we may find temporary marshes here and there. When a polar cap is melting quickly, in the Martian spring, a dark 'collar' is often seen round it, and this cannot be dismissed as a mere contrast effect, as has often been stated. G. P. Kuiper has written[1] that he "observed it with the 82-inch reflector under excellent conditions in April 1950, and found it black. . . . The rim is unquestionably real; its width is not constant, and its boundary is irregular".

Very probably this collar is due to marshiness around the melting border of the cap. It shrinks steadily as the polar snows re-

[1] *The Atmospheres of the Earth and Planets*, Chicago, 1952, p. 400.

PLATE XIII. Six views of Mars (1952, 12½-inch refl. ×360, Patrick Moore)

1. May 17, 20h. 25m.
2. Apr. 17, 1h. 15m.
3. May 17, 22h. 0m.
4. May 18, 0h. 5m.
5. Apr. 28, 0h. 0m.
6. Apr. 14, 1h. 20m.

Plate XIV. Eclipse of the Sun from Phobos. Mars 3,800 miles distant; diameter of planet 40°, visual angle 35°. (L. F. Ball)

treat, however, so that the marshiness must dry up fairly quickly; and it is not likely that anything in the nature of a true polar sea ever forms. Occasional pools of water are as much as we must ever expect to find.

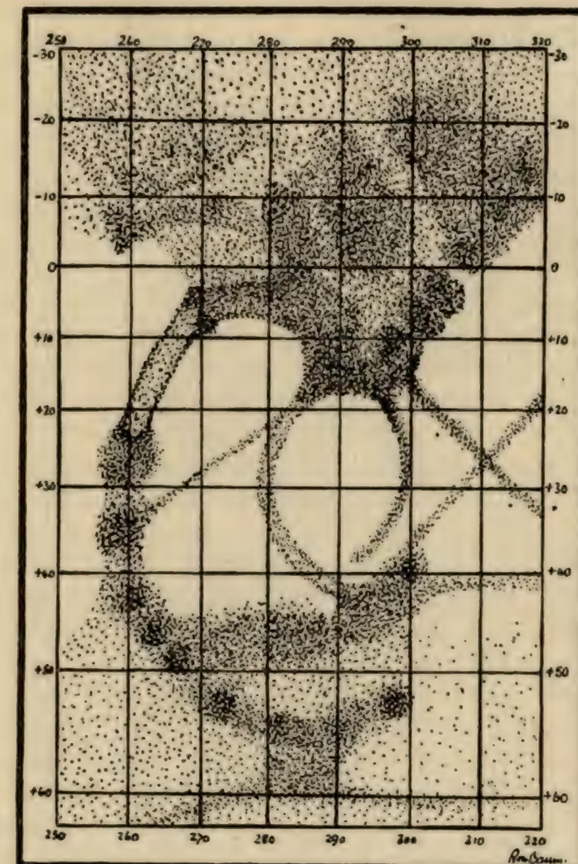


Fig. 14. A map of the region of Syrtis Major (from observations taken in April 1952; R. M. Baum, F.R.A.S.)

As the cap melts and a certain amount of water (whether in liquid or vapour form) is released, the darker areas in the temperate zones wake to life. A "wave of darkening", as Dr. de Vaucouleurs described it, spreads from the poles in the direction of the equator; the grey-greenish areas turn to brown, chocolate or

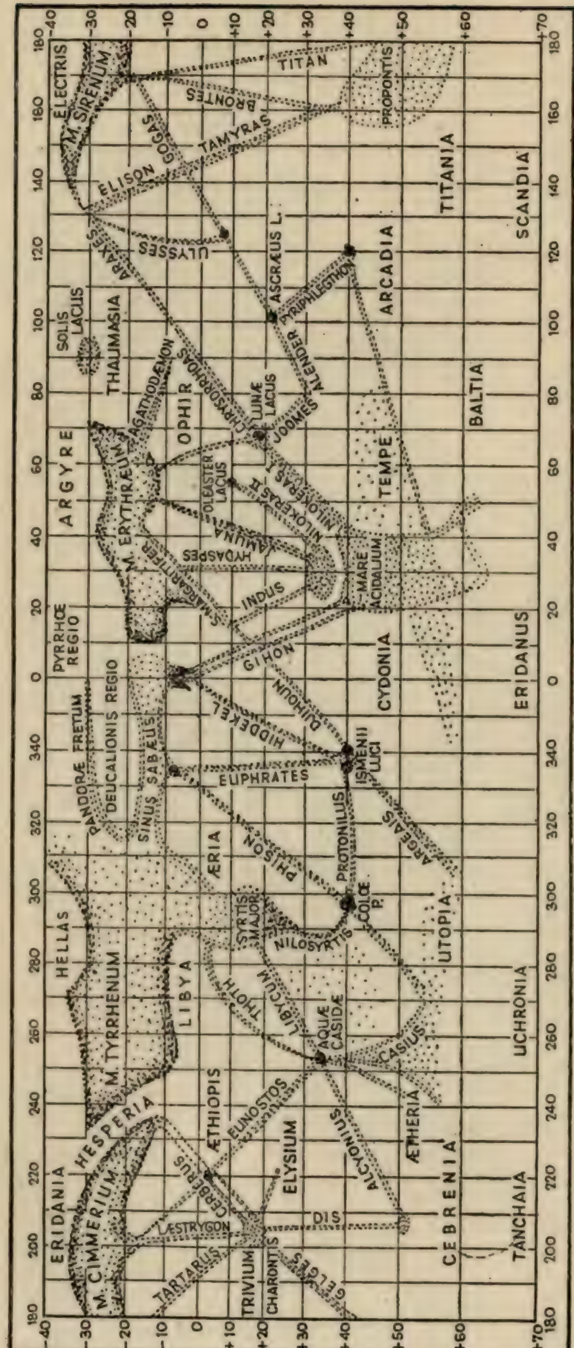


FIG. 15. Chart of Mars (from 49 observations, 37 drawings, made in 1935; Robert Barker, F.R.A.S.)

even carmine, as if the arrival of the welcome moisture has awakened the Martian plant life from its winter sleep.

Not all the dark areas are affected. Some respond more obviously than others, while a few remain permanently greyish-green. But we would expect local conditions to play their part in the seasonal cycle, just as is the case on Earth; and it is difficult to doubt that the dark areas are due to vegetation—a suggestion first advanced by Liais in 1878. Other theories have been put forward, but none seem very plausible, and in any case there is no need to go out of our way to search for an unlikely explanation when there is a reasonable one presented to us.

The main objection to the vegetation theory is that the spectroscope does not reveal the presence of chlorophyll, the green colouring matter of terrestrial plants. On the other hand there are some Earth plants, mainly of the lichen and moss families, which would not be expected to show visible indications of chlorophyll; and the eminent American scientist Dr. Hubertus Strughold, who has recently examined the problem from the point of view of the biologist, concludes that there is no serious obstacle to the idea that the dark areas are composed of vegetation.

Of course, there is no reason to assume that the Martian plants are entirely similar to ours. Their environment is different, and they have doubtless adapted themselves to it. The Russian astronomer Tikhoff is of the opinion that the lower mean temperature is responsible for the Martian vegetation absorbing the warming red and yellow light, and reflecting the blue and green rays—which would account for the characteristic winter colour of the dark areas. It is a fact that certain Arctic plants do behave rather like this.

Whether Tikhoff is right or not, there seems little serious doubt that plant life flourishes on Mars. Perhaps the strongest argument in favour of it has been given by Dr. E. J. Öpik, who has pointed out that material blown from the dusty deserts would long ago have overlaid and concealed the dark areas, had they no regenerative powers. For the second time in our imaginary journey outward from the Sun, we have found a planet which is a living world.

Despite its distance and its small size, Mars has been fairly

well charted. A modern map, drawn by R. Barker, one of the most experienced of British planetary observers, is reproduced in Fig. 15. The main details shown upon it can be picked up with telescopes of comparatively modest size.

Although the main outlines of the dark areas do not alter from year to year, or for that matter from century to century, smaller details do. Sometimes a dark area will undergo a slow, progressive change until it has altered its shape completely, after which it will change back again with equal slowness; sometimes there will be a comparatively rapid change, followed after a period of years by an equally rapid return to the old form. One region, the so-called Solis Lacus (Lake of the Sun), is notorious for its alterations. There is no mystery about them if we accept the plant hypothesis; they must be due to the spread and retreat of vegetation tracts.

Although the dark areas are not seas now, it is quite probable that they were seas millions of years ago, when Mars was a youthful, vigorous world with abundant air and water. Support for this idea is given by the fact that the vegetation tracts appear to be lower-lying than the deserts; and as Martian winds are quite appreciable, this provides additional support for Dr. Öpik's theory that nothing but vegetation could prevent the low-lying areas being covered by desert dust, and taking on the reddish-ochre hue of the rest of the planet.

It is also significant that the dark areas are appreciably warmer than the deserts. This, again, is only to be expected.

On Mercury and the Moon, perhaps on Venus also, there are mountains and valleys; but Mars is not a hilly world. Of course, it is not completely level – we cannot picture a planet with a totally smooth surface – but great chains of peaks, such as the terrestrial Himalayas or the lunar Leibnitz, are definitely absent.

The most recent work upon the problem of Martian relief has been carried out by Dr. Dollfus, at the Pic du Midi, who has tried to detect shadows cast by peaks near the terminator of Mars when the planet shows its maximum phase. So far he has been unsuccessful, which is hardly surprising in view of Mars' smallness and remoteness. It is rather like trying to find the shadow of an ant-hill when observing from an aeroplane flying thousands of feet above the ground.

The shrinking polar caps, however, give us some information. As they decrease, their borders become irregular; salients and notches appear, as would be expected upon a non-level surface. We would anticipate that snow would persist longest in the highest regions. From studies of these salients, Dollfus has calculated that there are plateaux at least 3,000 feet high in the polar regions, while one or two isolated white patches in more temperate zones probably mark peaks of even greater altitude. However, Mars has $\frac{2}{7}$ of the Earth's surface area; and if the mountains were as high, relatively, as ours, they would tower to something over 10,000 feet – which is certainly not the case. We seem here to have evidence of violent erosion in the past.

Although the polar caps and the dark areas combined cover vast tracts of the Martian surface, most of the planet is of the reddish-ochre hue which gives it its characteristic colour. From early times, these areas have been regarded as deserts; and in the broad sense, such an idea is probably correct.

However, the 'deserts' are certainly not sandy. Clyde Tombaugh, the American observer who discovered Pluto, has pointed out that there can be no true sand on Mars, since sand is the accumulation of soil and rock débris produced by running water – and running water is virtually unknown on Mars.

Dr. Lyot considered that Mars was coated with "a dusty cover analogous to that which covers the lands of the Moon", but it seems likely that the lunar covering is due to volcanic ash, and there is not much likelihood of extensive volcanic activity on Mars. Another suggestion is that the deserts are made of dust, coloured by metallic salts such as iron oxide (better known as common rust). This would account for their reddish colour, and also for the scarcity of oxygen in the Martian atmosphere; but the most recent investigations indicate that the surface coating is more likely to be made up of brownish, fine-grained felsite.

At all events, the reddish-ochre areas seem certainly to be 'deserts', far less fertile and productive than the darker tracts. Unlike our Saharas, they will be cold; and no welcoming oases will break their monotony. They must be incredibly dismal and lonely.

Judging from Mars' comparatively mild climate, the snows, and the vegetation tracts, it would not at first seem that we would

have much difficulty in living there once we had solved the problems of space-travel. Unfortunately, there is one great obstacle: the thinness of the atmosphere. It is true that there is a considerable air-mantle, but it lacks oxygen, and no human being could exist on Mars without erecting an airtight dome or wearing a breathing-mask.

There is no doubt about the actual existence of the atmosphere of Mars. Escape velocity there is over 3 miles a second, so that the Red Planet has been able to retain a considerable blanket of air. The atmosphere has even been observed. Barker, using his 12-inch reflector, once watched an occultation of Mars by the Moon, and as the planet disappeared behind the lunar limb, recorded that: "The last contact was followed by a comet-like misty appearance, almost $1\frac{1}{2}$ times the diameter of the planet, which also slowly disappeared behind the Moon", and he repeated the observation at a subsequent occultation.

However, the smaller gravitational pull of Mars has allowed more of the atmosphere to leak away than in the case of the Earth. If the early histories of the two worlds were much the same, as we have every right to assume, the hot and youthful Mars lost its original atmosphere in the same way as the Earth, and probably at the same epoch; there followed a period of cooling and intense volcanic activity, resulting in a planet with abundant water and a dense atmosphere. But the Earth's pull allowed it to retain almost all of its secondary atmosphere; Mars was unequal to the task.

The present state of things adds force to the suggestion that Mars is an ageing world. A good proportion of the air has leaked away, though much remains; the water has dried up, and the atmospheric oxygen has combined with the surface rocks. Intelligent life, if it exists, must see its end close at hand on the cosmical time-scale.

The ordinary terrestrial barometer is scaled for a pressure range of between 26 and 32 inches of mercury, but such an instrument would be of no use on Mars, where the pressure is much less. According to Dr. de Vaucouleurs, the mean value is about $2\frac{1}{2}$ inches of mercury, which is about the same as the pressure eleven miles above the surface of the Earth – in the lofty stratosphere, where no man may breathe. Of course, there must be some uncertainty as to the exact value, but de Vaucouleurs' result is certainly not far wrong.

Things are made even worse, from our point of view, by the fact that as well as being thin, the atmosphere is also oxygen-poor. To us, oxygen is the life-giving gas, and experiments made by Adams and Dunham at Mount Wilson, in 1933, led them to the conclusion that the Martian air contains less than a thousandth of the amount of oxygen in ours, volume for volume. This is now thought to be an under-estimate; but even so, oxygen is still in desperately short supply. Even if Mars' atmosphere proved to be much denser than we think, we should still be unable to breathe it.

A great many attempts have been made to find out the exact composition of the atmosphere, but so far we still rely largely upon guesswork. Nitrogen, which makes up most of our air, is very shy of revealing itself spectroscopically, and in the opinion of Dr. de Vaucouleurs the Martian air-mantle is made up largely of it. Nitrogen is, of course, harmless, so that we are unlikely to find anything toxic in the Martian atmosphere. Carbon dioxide has also been detected, and is rather more plentiful than in our own air; and in view of the melting of the polar caps, we cannot dispute the existence of some water vapour, though the precise amount is very difficult to determine.

Rainfall is certainly unknown upon Mars, but there are, nevertheless, clouds. In fact, clouds are by no means unusual, and can be divided into two main types, the so-called 'blue' and 'yellow' classes.

The 'blue' clouds do not appear blue to the eye; they are so called because they are best seen in photographs taken in blue light. As we know from the colour of our own sky, blue light is easily scattered, and has little penetrating power, so that photographs taken in it will show only the upper levels of the Martian atmosphere. The blue clouds are, therefore, at a high altitude; perhaps twelve miles is a good estimate. Needless to say, the temperature at this height in Mars' thin air is bitter indeed (about $-100°$ C.), and it is probable that the blue clouds are made up mainly of ice-crystals. If so, they must be very like our own fleecy cirrus.

The blue clouds are short-lived and frequent, but the 'yellow'

clouds, which really do appear yellowish to the eye, are very different. They lie at a much lower level, and sometimes obscure huge areas of the planet. In 1911, for instance, a vast yellowish veil was seen to extend over millions of square miles, and did not clear away for some weeks.

There are any number of reasons for believing that these yellow veils are totally unlike our own clouds. They cannot be watery, and must be composed of dust. The main puzzle about them is – how and why do they occur?

Terrestrial dust-storms are nearly always caused by wind. Winds do cut through the thin, cool air of Mars, but they are by no means violent, and a twenty-knot breeze would be almost a gale by Martian standards. It is not easy to see how a vast dusty veil, such as that of 1911, could be whipped up by air moving at such moderate velocity.

It is true that the 1911 cloud was of unusual size, and that most of the yellow clouds are comparatively small, but even from a distance of fifty million miles or more they can be quite conspicuous. They are observed at almost every opposition, and some of those recorded during 1951 and 1952 are worth describing as being typical of most of the rest.

On October 30, 1951, Japanese observers detected a yellow cloud moving steadily across the Martian surface. It had an average speed of about 13 knots, and vanished on November 8. A second cloud seen later in November, also by Japanese observers, was quicker-moving (about 20 knots) and almost as persistent. Some months later, on 1952 March 27, when Mars was closer to the Earth and therefore better placed for observation, an even larger cloud was detected by two German astronomers, Dr. Sandner and Dr. Kutscher, and followed until April 10. On 1952 May 17, a bright yellow cloud close to the dark area known as Mare Acidalium was seen by Dr. Wilkins and myself, and became a striking object, though it does not seem to have lasted for more than a day or so.

Unfortunately, we are rather at a loss to account for the yellow clouds if we reject the idea of wind-inspired dust-storms. Volcanic eruptions have been suggested, but here again we run into grave difficulties. Mars has aged too much for violent vulcanism to be expected. It is also noticeable that volcanic activity seems to be

PLATE XV. Two views of Jupiter (*above:* 1933, Mar. 9, L. F. Ball; *below:* 1949, Aug. 11, 23h., 10-inch × 262, L. F. Ball)

Plate XVI. Jupiter from its satellite Io. Jupiter 261,800 miles distant; diameter of planet 22°, visual angle 35°. (L. F. Ball)

bound up in some way with water – all terrestrial volcanoes lie fairly near the sea – and, as we know, there is not much water left on Mars.

Great interest was aroused in late 1951 by an unusual observation made by Tsuneo Saheki, one of Japan's leading planetary observers. At 21 hours G.M.T. on December 8, he detected a small, starlike spot over the area known as Tithonius Lacus, not far from the south pole. During the next few minutes it decreased in brilliancy and became larger, finally fading out in less than an hour (Fig. 16A). Clearly something unusual had taken place, and a number of somewhat unlikely explanations were offered in the Press. One reputable daily paper went so far as to suggest that the Martians were trying to communicate with us by means of flashing mirrors, and another considered it possible that an atomic bomb had been exploded. The landing on Mars of a large meteorite was also suggested, but even a giant body such as the Siberian meteorite of 1908 would have been quite unable to produce such a glow; and on the whole it seems reasonable to assume that the phenomenon was due to some unusual cloud formation.

In short, all we can say about the yellow clouds is that they are probably made up of dust particles. We do not yet know their exact composition, nor can we be sure how they arise.

Many books have been written about Mars, and this survey of the main surface features is necessarily short and incomplete. Before we turn our attention to the so-called 'non-natural' features, however, mention must be made of the two tiny moons, perhaps the most remarkable satellites in the entire Solar System.

Up to 1877 it was believed that Mars, like Mercury and Venus, was moonless; but in that year Professor Asaph Hall, at Washington, discovered two dwarf attendants which were subsequently named Phobos ('Dread') and Deimos ('Terror'), after the two servants of the mythological War-God. As a matter of fact Dean Swift, in his immortal *Gulliver's Voyages*, had already predicted them, and so had Voltaire in his *Micromégas*, but it is quite certain that they had never been glimpsed before 1877. Even when Mars is at its closest, they cannot be seen except with fairly large telescopes. I have glimpsed Phobos with my $12\frac{1}{2}$-inch reflector, and both satellites with Dr. Wilkins' $15\frac{1}{2}$-inch, but not easily.

FIG. 16A (*above*). A curious bright spot on Mars (1951, Dec. 8; Tsuneo Saheki)

FIG. 16B (*left*). An unusual cloud seen on Mars by Tsuneo Saheki, 1950, Jan. 16

Phobos and Deimos are very small indeed – so small that their exact diameters are rather uncertain. Phobos is in the region of ten miles across, and Deimos six; so that if such a thing were possible it would take only a few hours to walk right round either. Actually, however, it would be impossible to 'walk' there in the conventional manner. The surface gravities are so low that a man would weigh less than an ounce, and the slightest jump would send him sailing high into space.

Even to an observer on the Martian surface, the satellites would appear far from brilliant. Phobos would have an apparent

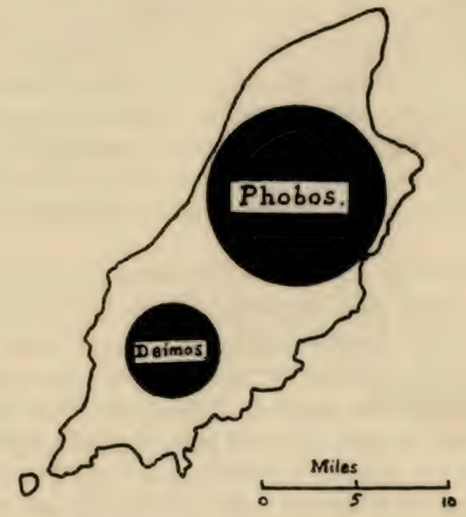


FIG. 17. Sizes of Phobos and Deimos, compared with the Isle of Man

diameter of one-third that of our Moon seen from the Earth; Deimos, smaller and farther out, would be much more like Venus as seen by us. Moreover, Phobos at least could never be seen at all from high latitudes, and neither can be very effective at cheering the darkness of the Martian nights.

Both Phobos and Deimos move in a most peculiar fashion. They have been described by mathematical astronomers as 'dynamical nightmares', and with good reason. Phobos is perhaps the odder of the two. For one thing, it is remarkably close to Mars – a mere 3,700 miles above the surface; only about as

far as from London to Aden – and it goes round the planet in 7 hours 39 minutes, which is only one-third the length of the Martian day. This short period of revolution results in some very curious phenomena. To an observer on Mars, Phobos would appear to rise in the west and race across the sky, setting in the east only 4½ hours later; and in this lightning passage across the heavens, it would pass through more than half its cycle of phases. If it rose as a thin crescent, it would be nearly full before it set. The interval between successive risings would be only about 11 hours.

Deimos is equally strange in its own way. It is much farther out – about 12,500 miles above the surface, equal to the distance between England and Australia – and its period of revolution is 30 hours, which is longer, but not much longer, than the Martian day. As Mars spins, therefore, Deimos almost keeps pace with it, falling behind only very slowly; and consequently it remains above the horizon at any one time for 2½ Martian days at a stretch, during which period it goes through all its phases twice.

These bewildering little moonlets undergo all sorts of eclipse phenomena. They pass in and out of the shadow of Mars; Phobos may occult Deimos; and a Martian observer would also see frequent solar eclipses – or should they be called satellite transits? When Phobos passes in front of the Sun, which it does some 1,300 times in each Martian year, it covers one-third of the solar disk, but the eclipse is rather a hurried affair, over in only 19 seconds. Deimos passes in front of the Sun 120 times a year, but it covers only one-ninth of the disk, and moves at a more leisurely rate, taking almost two minutes to complete its transit.

As neither satellite appears large enough to cover the whole disk of the Sun, even though the solar face as seen from Mars is considerably smaller than as seen from Earth, the Martian astronomers – if they existed – could never have the privilege of seeing the Sun's outer atmosphere, with its corona and red prominences, with the unaided eye.

Some time in the future, terrestrial scientists will undoubtedly construct 'artificial satellites' or space-stations, man-built worlds circling the Earth well above the outer limit of the effective atmosphere. It is impossible to avoid commenting on the fact that

Nature has provided Mars with two perfect ready-made space-stations, and it has even been suggested that the first visitors from Earth may find that Phobos and Deimos are constructed of steel rather than the more orthodox rock! It is certainly an attractive idea, even though we must regretfully class it with Gruithuisen's celebrations on Venus, H. G. Wells' moon-men, and recent theories about flying saucers.

But although we must certainly dismiss the idea that Phobos and Deimos are artificial, can we say as much about those strange and unique features, the Martian canals?

The story of the canals begins as long ago as 1877, the year in which Professor Hall first detected the two satellites. Mars was well-placed for observation, and Giovanni Schiaparelli, a celebrated Italian astronomer, began to make a close study of it. He was using a good 8¾-inch refractor, the Italian skies are clear and dust-free, and there is no doubt that Schiaparelli himself was a first-class observer and draughtsman, so that in 1877 and the following two oppositions (those of 1879 and 1881) he was able to draw up charts of the planet far superior to any previously constructed.

In addition to the well-known light and dark areas, and of course the polar caps, Schiaparelli discovered other features which puzzled him considerably. The ochre tracts appeared to be crossed by numbers of fine, dark lines. These lines were invariably straight; they ran from dark area to dark area; they never stopped abruptly in the middle of a desert, and altogether they looked quite unlike anything else in the planetary system. Schiaparelli called them 'canali' – or, in English, 'channels'. Where they intersected, as they often did, were small darkish patches which Lowell later christened 'oases'.

It is often stated that Schiaparelli himself was convinced that the features were natural, and the very name of 'canal' a gross mistranslation. This view is not entirely correct. Schiaparelli was careful to keep a completely open mind. He certainly believed that the canals were great ditches in the planet's surface, utilized – whether naturally or not – for the passage of water from the snowy poles to the arid desert regions. Towards the end of his career, indeed, he wrote that "their singular aspect has led some to see in them the work of intelligent beings. I am very careful

not to combat this suggestion, which contains nothing impossible."

No other observer succeeded in detecting the canals in 1877 or 1879, and Schiaparelli's observations were still unconfirmed when, in 1881, he came across another extraordinary fact. Some of the canals, previously seen as single lines, turned abruptly into twins. In place of the original canal, two canals were seen – strictly parallel through their length, and in every way similar. Sometimes one component occupied the original site; sometimes the two components lay to either side of the track of the original canal.

Not all the canals showed this curious doubling (or 'gemination', to give it its technical name). Only a certain number of canals were affected, and then not all at the same time. When doubling took place, it did so suddenly and completely. A canal which had been single one night might appear as a perfect pair the next. Nor were the separating distances the same; some pairs were divided by as much as four hundred miles, others by as little as fifty.

It is hardly surprising that Schiaparelli's discoveries were treated with a good deal of scepticism, and for some years it was generally believed that he had been the victim of some curious illusion. But in 1885, two French astronomers, Perrotin and Thollon, using the large refractor of the Observatory of Nice, announced that they had confirmed Schiaparelli's observations. A. S. Williams, in England, followed; and gradually other observers were equally successful, until the real existence of the canal network was regarded as more or less established.

Schiaparelli himself ceased all practical work in 1890, owing to failing eyesight (it is tragic to record that in his last years he became completely blind), but the problem was attacked with great energy by Professor Percival Lowell, who founded an observatory at Flagstaff, in Arizona, specially for planetary work. Between 1894 and 1916 he accomplished a great deal in all branches of astronomy, but his name will always be linked with the canals of Mars.

Lowell was quite definite in his views. He considered that the canals were artificial, constructed by intelligent beings to convey water from the ice-capped poles to the waterless desert regions.

To Lowell, therefore, Mars was the abode of life even more advanced than our own.

It is quite true that many of the observed phenomena could be explained on this theory. We would expect the canals to be at their faintest in the Martian winter, increasing in visibility with the melting of the caps; the doubling of the canals could also be accounted for, as if one channel proved inadequate to cope with the available supply another channel, close to the first, could be opened at short notice. Of course, pumping stations would be necessary, and the construction of a planet-wide engineering project on this scale would involve tremendous technical difficulties, even when we take into account Mars' gravitational pull and lack of mountain ranges.

Lowell never suggested that the canals themselves were channels of open water. For us to see them at all, over a minimum distance of 35 million miles, they must be at least thirty miles broad; and water-channels of this magnitude, open to the atmosphere, would result in crippling losses by evaporation. In any case, the Martian polar caps certainly do not contain enough water to fill such tremendous ditches. Lowell's picture was of a comparatively narrow water-channel, probably piped, flanked on either side by a strip of irrigated land.

Lowell's maps of Mars were, indeed, most peculiar. He showed the canals as extremely narrow, perfectly straight, and very numerous; he noted over 700 altogether, crossing not only the deserts but also the dark areas. In fact, his canal-system was too regular to be the work of Nature. Acceptance of Lowell's charts necessarily involves acceptance of his whole theory.

However, few astronomers do accept Lowell's charts. Even when first published, they were challenged by other equally skilled observers who could see absolutely no trace of the canal network. Professor Barnard, using equipment superior to Lowell's, could see only broad, diffuse streaks where Lowell drew sharp lines; and other observers were even less successful.

There never was, and never has been, any suggestion that Lowell was deliberately drawing on his imagination. Such an idea is absurd. Unfortunately, there are one or two disquieting facts. For one thing, Lowell drew linear streaks not only on Mars, but also on Mercury, Venus and the satellites of Jupiter. It is quite

true that he stressed that the linear features on these bodies were quite different in aspect from the Martian ones, but, even so, his chart of Venus can only be described as fantastic; the features shown simply do not exist, and he was mistaken, too, about the straight streaks which he drew on Mercury. If he was entirely wrong in two cases, it is logical to assume that he was also wrong in the third.

A possible explanation is that the human eye tends to join up disconnected spots and streaks into hard lines, and this was the view taken by Maunder, the English astronomer who was largely responsible for founding the British Astronomical Association. In 1902, Maunder conducted an interesting experiment. A drawing of Mars, without canals but with indistinct shadings and roughly aligned dusky patches, was shown at a distance to a class of boys from the Greenwich Hospital School, who were told to copy it. None of them had any knowledge of astronomy, but when the drawings were collected it was seen that many of the boys had put in fine, linear streaks. Lowell dismissed the experiment contemptuously as the "small boy theory", and my own investigations have not supported it,[1] but there is no doubt that the human eye tends to become unreliable when straining to see details at the very limit of visibility.

Photography is of no help. The canals can only be detected at moments of perfect seeing, and the slightest disturbance in the Earth's atmosphere will blot them out, which renders all time-exposures – even those of only a few seconds' duration – useless.

Lowell's final book, *Mars and its Canals*, was published in 1908, and it is safe to say that no other scientific volume ever produced has given rise to so much argument. One school of thought held that Lowell's charts were completely accurate; other observers contended that the canals were completely illusory, and had no real existence. Some astronomers could see the artificial-looking network, and described it as clear and continuous; others could see no trace of it. Such was the position in 1916, when Lowell himself died.

[1] I repeated the experiment in 1950. The boys, pupils at Holmewood House preparatory school near Tunbridge Wells, were younger than Maunder's, but of a higher educational level; and out of fifty-eight drawings only three showed canals. It is significant that of these three boys, two were notoriously inartistic and the third short-sighted.

Many of the observers who drew canals in Lowell's style were equipped with comparatively small telescopes, and it was even maintained that a small instrument was more likely to produce good results than a large one – because a high power magnifies the atmospheric tremors, with consequent blurring of fine detail. This view is unreasonable, and was attacked by E. M. Antoniadi, who was quite unable to see the canal network even with the great 33-inch refractor at Meudon. In 1930, Antoniadi wrote: "No-one has ever seen a true canal on Mars. The rectilinear canals of Schiaparelli, single or double, do not exist . . . though they have a basis of reality, since all are situated either on spotted irregular tracks or rugged grey borders."

There is no point in going into more detail about the heated arguments that went on for over forty years following the publication of Lowell's book. Much sense was written, and also much nonsense. Now, at last, we have some observations which seem to shed real light on the whole problem.

These observations have been made by Dr. Dollfus, perhaps the leading planetary observer of modern times, at the Pic du Midi, where the seeing is as good as that found anywhere in the world. Using the 24-inch refractor under perfect conditions, Dollfus found that the linear features dissolved into fine structure of spots and patches – though the slightest atmospheric tremor made them harden and sharpen once more into conventional 'canals'. This, then, seems to be the correct answer. The canals are made up of roughly aligned spots and streaks, and the artificial aspect of the network as drawn by Lowell is exaggerated out of all proportion.

Even so, the canals in their modified form are still very curious objects. They are definitely not pure illusions, and they need explaining. Though Lowell's theory of intelligent beings has not a scrap of proof, we cannot dismiss it entirely; a strip of irrigated land to either side of a piped waterway would indeed show up in much the form described by Dollfus. The doubling of the canals, too, remains a mystery. If the canals are not artificial, what are they?

Probably they are natural features. If they are depressions, such as long, shallow valleys, vegetation may be expected to flourish in them, and this would account for their darkening

during the Martian spring. Even if we discount any water-flow, the melting (or sublimation) of the caps must unlock a good deal of water vapour, and this, carried by winds, might well be enough for the needs of the plants. D. L. Cyr has suggested that the 'oases' are craters similar to those of the Moon, and that the canals are giant clefts; but this seems rather far-fetched, owing to their great breadth.

Moreover, Dr. Öpik's comment upon the fact that the dark areas would soon be overlaid with dust, unless they are composed of vegetation, applies with equal force to the canals. On the whole it seems that vegetation of some sort is the best answer; and this is as far as we can go at present.

All things considered, Mars is undoubtedly the most fascinating of all the planets. It is basically similar to the Earth; it is tolerably warm; it has atmosphere and water; and it has vegetation, so that even if it has long since passed the prime of life it is still far from being a dead or even a dying world. Though it is true to say that we have no proof of intelligent life upon it, it is equally true to say that we have no proof that advanced forms of life do not exist.

CHAPTER 9

The Martian Base

It is going to be no easy matter to reach Mars. The younger men of 1954 may well live long enough to see the first voyages to the Moon, but even this is very far from certain – and the Moon is the Earth's companion, not a totally alien world.

Even at its closest, Mars is more than a hundred times as distant as the Moon; and although sheer distance is not particularly important in itself – the extra fuel needed for the Martian trip as compared to the lunar one is not so much as might be expected – the associated problems are obviously increased. For instance, there is a greater danger from meteors. Space contains millions upon millions of these tiny pieces of rock, whirling round the Sun; and although it will be possible to protect interplanetary craft from all except the occasional 'giants', we shall have to expect a disaster every now and then. Long exposure to cosmic rays and harmful radiations from the Sun, which are cut off from the Earth's surface by the shielding ozone layer in our atmosphere, will also have to be taken into account.

By the time that the first Martian expedition sets off, it is to be hoped that the minds of men will have developed beyond the stage of petty quarrelling. All the same, the crew of the first space-craft will have to be very carefully chosen. They will see a great deal of each other, as the voyage will last a long time; according to present calculations it will take nine months to reach Mars and another nine to return, while the explorers will have to spend some sixteen months on the planet itself before conditions are favourable for the trip home. The total time taken, therefore, will be over two years.

It is improbable that the Martian expedition will start from the surface of the Earth. It may leave from the Moon, but more probably from an artificial satellite circling the Earth. However, the exact point of departure makes little difference to the time taken for the voyage, and unless we can attain improbably high speeds we must resign ourselves to a lengthy absence.

Owing to the fact that it will be necessary to spend over a year on Mars itself, it is clear that we shall have to construct some sort of base; and as a matter of fact this should present few major difficulties. Mars itself may provide essential materials; and although the Base must begin in humble fashion as a mere group of pressurized huts, it should be capable of quick development. The Base of the far future, headquarters of the colonists of the planet, will be extensive. Men may spend all their lives there, and, perhaps for the first time in its history, Mars will be a world controlled by intelligent minds.

Needless to say, we are looking centuries ahead. The first Martian expedition may be on its way by the year 2100; the Base may have been established by 2150; by 2200, much of the planet may have been explored, and reconnaissance parties sent out to Venus. Almost certainly the Moon, at least, will have been conquered. But it is unwise to make any attempt at accurate forecasting; our time-scale may be wildly wrong, as many problems remain to be solved before we can even think of taking our first leaps into space.

However, the possibility is unquestioned; whether it will be realized or not is entirely in our own hands. At least, it will do no harm to speculate a little. Let us imagine, therefore, that we have gone forward to the year 2200, and that we are about to pay a visit to the Martian Base.

We start our journey not from the Earth itself, but from one of the 'space-cities' built by men. There are several of these space-stations, and one, revolving round the Earth at a distance of about 3,000 miles above the surface, is used almost entirely as a rocket port for interplanetary craft.

The space-ship in which we travel is totally unlike the sleek, streamlined craft of twentieth-century writers. It is not streamlined at all, as it never encounters air; it was built in outer space, and it has spent all its life in space. It has never landed upon any large world, and would in fact be quite unable to do so, so that we shall not go direct to Mars. We shall call first at Deimos, the outer of the two tiny satellites.

By the time our long journey is nearing its end, and the Red Planet looms ahead of us – no longer a mere disk, but a gigantic reddish-ochre globe, patched and streaked with tracts of bluish-green and capped by the brilliant snowfields – we have become used to weighing nothing, and even when we step on to the surface of Deimos we notice no change. The escape velocity of the dwarf world is so low that 'walking', in the proper sense of the word, is out of the question; our weight is reduced to less than an ounce.

This involves our wearing a space-suit fitted with a rocket motor, and, incidentally, this suit is far from comfortable. The old idea of flexible, insulating clothing, on the lines of a diver's suit, has had to be drastically revised. For the diver, all the pressure comes from the outside; in space there is no outer pressure, and a flexible suit would be unable to stand up to the strain. It would tend to spread-eagle the wearer, with lethal results. Of course, Deimos has no air, so that our vacuum-suit is built like a rigid cylinder, with the arm-joints mechanically controlled.

But even though Deimos itself lacks variety, the view of Mars is well worth our nine months' journey. We have arrived at 'full Mars', and the Red Planet hangs in the black, star-studded sky, a magnificent globe 32 times as large as the Moon appears from the Earth. The brilliant marslight casts a strange, ruddy radiance over the miniature world on which we stand, and we can clearly see the wedge-shaped vegetation tract known as the Syrtis Major, where the first beginnings of the Martian base were constructed in the year A.D. 2150 – half a century ago. To the east there are other dark areas, the Sinus Sabæus particularly prominent, and to the north lie the ochre desert regions of Æria, Arabia and Elysium. The so-called 'canal' of the Nepenthes-Thoth can also be seen, but from our present distance of a mere twelve thousand miles even binoculars will show that it is not a hard, sharp feature. It is made up of disconnected spots and streaks, and runs northwards into the polar vegetation tract which has received the rather inappropriate name of Utopia.

Even after an hour or so, the Syrtis Major is still almost in the middle of the visible disk; this is because Deimos is keeping pace with Mars as the planet rotates on its axis. Very slowly, the markings move across the orange face from west to east, and very slowly, too, the phase alters; 'full Mars' gives way to 'gibbous

Mars', and if we wait long enough we shall see 'half Mars'. Once, too, we see Phobos, the inner satellite, passing in front of the Martian disk, looking very small and insignificant even though it is only 9,000 miles from us.

From Phobos, Mars would indeed be a superb spectacle. It would have 82 times the apparent diameter of the Moon seen from Earth, and would extend half-way from the horizon to the zenith! The markings would drift across the disk from east to west, as a result of Phobos' peculiarly quick 'month', and the phases would be run through in remarkably short time. Sometimes, too, the Sun would be eclipsed by the great disk of Mars, so that the Red Planet would appear as a dark mass in the sky ringed by a glorious, gleaming aureole caused by its atmosphere.

But we must not delay. A 'transit rocket' is waiting for us, and so we come down on to Mars itself—landing in the Syrtis Major, close to the spot where the main Martian Base has been built.

It is a relief to be able to dispense with our vacuum-suits. We are near the equator, and the Sun is high in the sky, so that the temperature is very comfortable—a thermometer would register over 60° F. Even though the Martian air is much too thin and oxygen-poor for us to breathe, it exerts considerable pressure, and during the hottest part of the day we can walk about quite safely with no more equipment than an oxygen-mask. Needless to say, the atmosphere also affords adequate protection from meteorites, and from the undesirable short-wave radiations sent out by the Sun.

Almost the first thing we notice is the colour of the sky. It is not inky black, as in space and on Deimos, but neither is it much like a terrestrial sky. It is dark blue in colour, Oxford rather than Cambridge, even near the zenith; this is because the thin Martian air is much less effective than ours at scattering light. Another result of this is that the Sun is whiter than as seen from the Earth, as well as appreciably smaller. The Earth's atmosphere scatters a great percentage of the bluish light, leaving the Sun only its yellow and red rays; but this effect is considerably modified on Mars.

Automatically, we look round the dark blue sky for stars, but none are to be seen; none, in fact, are to be expected. Contrary

to the old belief, stars and the Sun cannot be seen simultaneously even from the Moon, unless the glare from the surrounding rocks is screened. In any case, the Martian sky is much too bright for stars to be seen before sunset.

The next thing that strikes us as unusual is our sense of lightness. Zero gravity has become familiar during our long journey through space, but when we land again on a large planet we half expect to find ourselves back to 'normal'. Once again, we are wrong. A spring balance, which does not depend upon gravity, shows us that we retain only one-third of our terrestrial weight, and we can jump about with surprising ease. A ten-foot leap is not difficult, and, moreover, we land quite gently. A fall which would be fatal on Earth would be no more than uncomfortable on Mars.

As we know that the space-port is only a few miles away from the main Base, we look round eagerly for our first sight of it; but it is not in view, and almost at once we realize why. Mars is a much smaller world than the Earth, and its surface curves more sharply, so that the horizon is correspondingly nearer; and even though the land seems flat, we can only see about three miles. However, our rocket has been met by a small, unusual-looking car equipped with a pressurized cabin, and this will take us along the road which has been constructed between the space-port and the Base.

It is clear at once that the Syrtis Major is not a forested or even a wooded area. There is vegetation in plenty, but most of it is of the lichen and moss type, though here and there we come across higher plants which seem to be distant relations of the desert cactus. Obviously, we can only expect to see plants which can manage to do with very little water. Millions of years ago, in its youth, Mars was a fertile and fruitful planet; but by now most of the water has dried up and the air leaked away, so that the only vegetation to survive is that which can do with a vanishingly small supply of moisture. Indeed, the plants depend largely upon water-vapour wafted by the winds from the melting polar caps.

And what of the 'Martians'?

No traces of them have been found, despite the most careful search. The new colonists have done their best to discover the remains of the old peoples and old cities, but without success,

and the Martians seem finally relegated to the land of make-believe. It is only now, in its old age, that Mars knows intelligent life.

All this time we have been driving briskly across the Syrtis Major, and by now the Base is in full view. Broadly, it consists of five or six domes, constructed of strong plastic material and kept up by the pressure inside them, like so many air-bubbles. We enter by an air-lock, and find ourselves inside the headquarters of modern Martian civilization.

Once safely inside, we can dispense with our oxygen masks. The atmospheric pressure has been raised to normal terrestrial value, and apart from our curious sensation of lightness it is difficult to realize that we are not on Earth. Of course, inside the Base there is no weather[1] in the proper sense of the word, as the temperature is automatically regulated, and the immensely tough plastic skin affords complete protection against the bitterest cold outside.

Each dome of the Base covers several square miles, and each is independent, with its own air-lock system. This is a safety precaution; if the air supply in one dome failed for any reason, the inhabitants could be evacuated quickly into neighbouring domes while repair squads dealt with the trouble. Such an emergency is extremely unlikely, but all things are possible, and it would be sheer folly to be caught unprepared.

Some foods still have to be brought from Earth, and even now the 'Martians' have to tolerate a good many unappetising concentrates, but terrestrial plants are adapting themselves well to conditions inside the Base, and the food situation is gradually being eased. There are even a few Earth-plants which have managed to survive outside, in the open air, though it will take many years and hundreds of generations for them to adapt themselves properly.

There is much to see inside the great domes, but if we want to visit the outer desert before nightfall we have no time to lose. We have been on Mars for some hours; the afternoon is well advanced, with the Sun sinking towards the horizon. This means that we can no longer venture out with an oxygen-mask only.

[1] This may prove inconvenient to Englishmen, who will thus be deprived of their main topic of conversation!

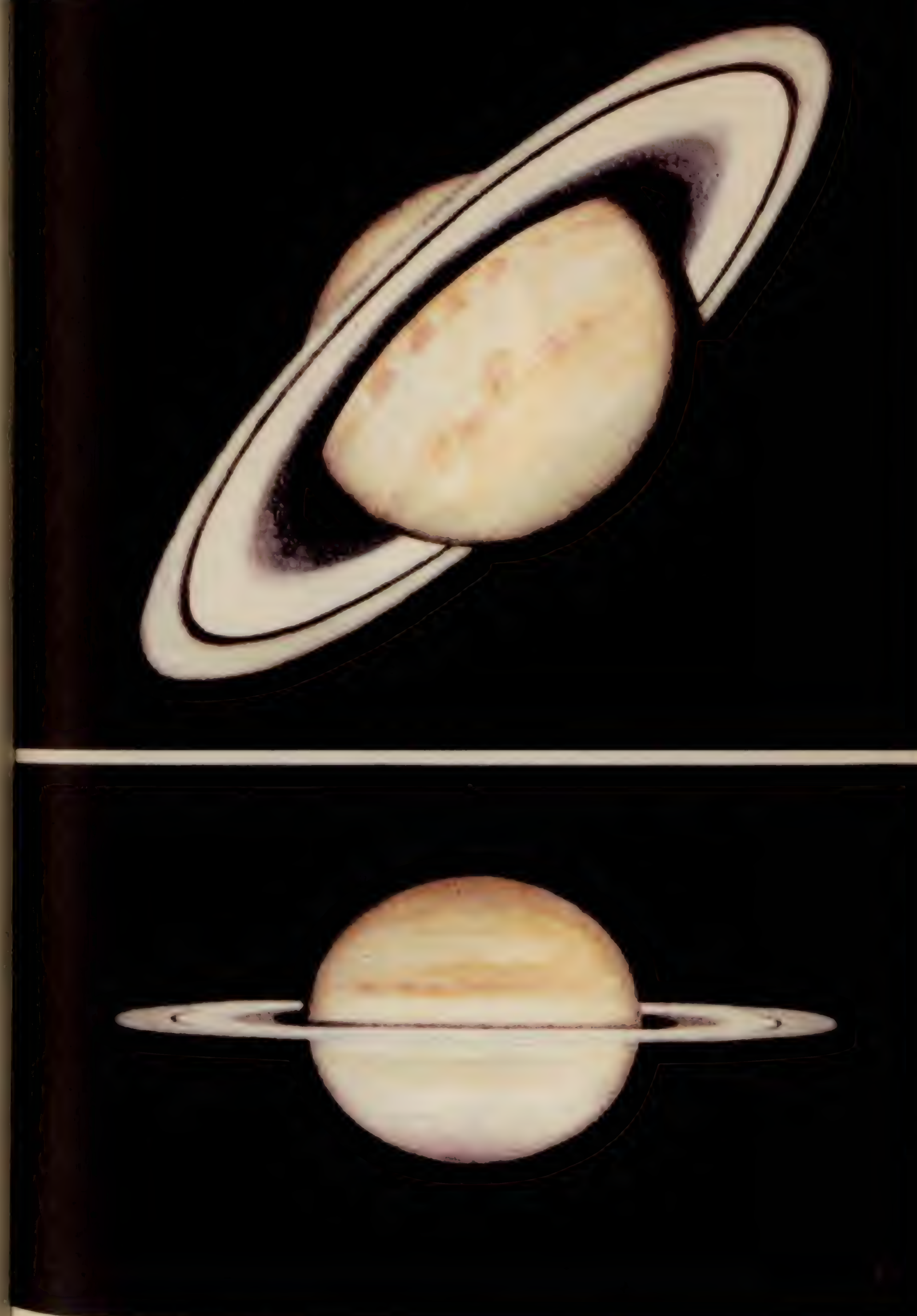


PLATE XVII. Two views of Saturn (*above:* 1932, Sept., L. F. Ball; *below:* 1950, Feb., L. F. Ball)

PLATE XVIII. Saturn seen from its satellite Rhea. Saturn 327,000 miles distant; apparent diameter of planet and rings 29°, visual angle 35°. (L. F. Ball)

The temperature has fallen to far below zero, even though it is near midsummer; and to go outside the dome without adequate protection would be inviting frostbite in its most violent and deadly form. Accordingly we equip ourselves with insulating suits, and drive through the air-lock in one of the pressurized cars which are used for almost all transport on Mars. Within an hour we have passed the limits of the Syrtis Major vegetation tract, and find ourselves alone in the dusty wastes beyond.

It is difficult to paint an adequate word-picture of the intense wildness and loneliness of the Martian desert. As we give our oxygen equipment a final test and step out on to the surface of the planet, we see that the ground beneath our feet is not sand; it is dust – hard, rusty-looking dust. This, then, has been the fate of most of the atmospheric oxygen. It has combined with the surface rock and literally rusted it, sounding the death-knell of all but the toughest and lowest forms of plant life.

In all directions, north, south, east and west, we can see nothing but the dusty desert. No plants break the monotony, and there is only a suspicion of movement in the chilly air; we cannot bring ourselves to believe that this eerie landscape can ever have been the scene of virile activity. A hushed, deathly silence broods over it now, and even if we were not wearing masks our voices would sound weak and far-away; the tenuous Martian air is a poor carrier of sound-waves.

The Sun has almost set. The sky has turned from dark blue to nearly black, and stars have begun to appear – hard, unwinking, and somehow unfriendly. We look for Phobos and Deimos, but before we have found them a thin shrilling of wind warns us that a dust-storm is at hand. Quickly we clamber back into our car; the tough plastic skin, transparent and fragile though it looks, is an efficient safeguard, and for some minutes we watch the whipping dust flash past. The wind has reached gale force, but a Martian gale is a comparatively mild affair, and an anemometer would register a bare thirty knots. There is certainly no danger of our car being lifted bodily and carried away.

By the time that the dust-storm has passed, and the sky is clear once more, the Sun has gone. There is almost no twilight on Mars, and the stars gleam forth in all their splendour. There are other interesting things to be seen, too. Phobos, now in its

crescent stage, is rising in the west, moving so quickly that we can almost see it creeping across the heavens; Deimos is full, but even so it looks like little more than a very brilliant star, and the two satellites together cast but a pale radiance across the silent wastes.

What of the planets? It is almost impossible to see Mercury from here; Venus is never very conspicuous, but low down in the west, not far from Phobos and moving the opposite way in the sky, is a bright, bluish-green star which we do not at once recognize. It is not until we detect a much smaller point of light close beside it that we realize that we are looking at our own home, the Earth, and its faithful Moon.

The dust-storm has passed; the wind has died, and the mantle of night has fallen across the gloomy, ice-cold waste. No animals roam the deserts of Mars; no winged creatures sweep through the thin, chill air; but beyond the horizon, far away across the plain, we can see a faint glimmer in the sky, telling us that men from the Earth have at last crossed the barriers of space to bring new life to a world from which all higher forms of life had long since faded.

Such is the picture of a Martian Base, seen from across the years. In 1954, it is still fantasy; in 2200, part of it, at least, may be fact. We stand now at the crossroads. If we use science for self-destruction, another century may see mankind back in the Stone Age; if we choose our leaders wisely, and use our scientific knowledge in the way that it should be used, it may lead us to—the Martian Base.

CHAPTER 10

The Minor Planets

Mars is the outermost of the four so-called 'terrestrial' planets. Beyond the Martian orbit, there is a 350-million-mile gap before we come to Jupiter, first of the giants; and this gap in the Solar System was noticed in comparatively early times. Kepler, the great mathematician who first discovered the Laws of Planetary Motion, suspected that the solar family was incomplete, and went so far as to write: "Between Mars and Jupiter I put a planet".

It was clear enough that even if such a planet existed, it could not be large. Even a world the size of the Moon would be readily visible without a telescope at all. But the problem of the missing planet was brought into prominence in 1772 by a German astronomer named Bode, who drew attention to a curious numerical relationship which had been discovered some years earlier by another German, Titius of Wittenberg. Rather unfairly, perhaps, it is known as Bode's Law, and is interesting enough to give in full.

Planet	*Distance by Bode's Law*	*Actual distance*
Mercury	4	3·9
Venus	7	7·2
The Earth	10	10
Mars	16	15·2
—	28	—
Jupiter	52	52·0
Saturn	100	95·4
Uranus	196	191·8
Neptune	—	300·7
Pluto	388	394·6

Take the numbers 0, 3, 6, 12, 24, 48, 96, 192 and 384, each of which (apart from the first) is double its predecessor. Now add 4 to each, giving: 4, 7, 10, 16, 28, 52, 100, 196, 388. Taking the

Earth's distance from the Sun as 10, this series of numbers gives us the distances of the remaining planets, to scale, with amazing accuracy. The table above will make this perfectly clear.

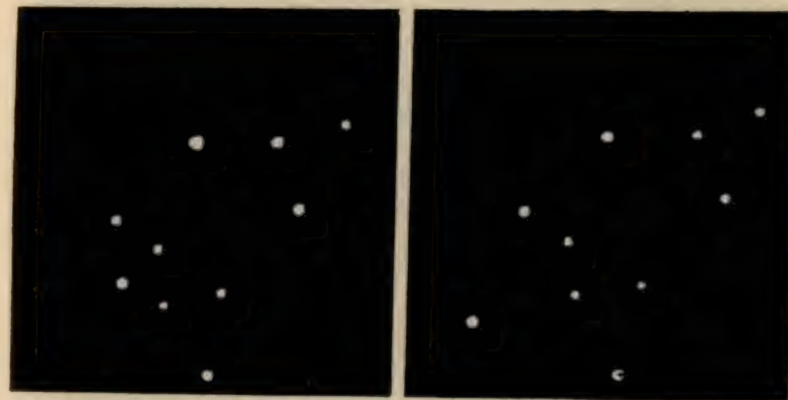
The three outer planets, Uranus, Neptune and Pluto, were not known when Titius worked out the relationship; but when Uranus was discovered, in 1781, it was found to fit excellently into the general scheme. Neptune, admittedly, is a 'problem child'. According to Bode's Law, it ought not to be there, and the last figure (388) corresponds well enough to the actual mean distance of Pluto. But at the time of its discovery the Law was almost as perfect as laws ever are – except for the missing planet corresponding to figure 28.

In 1800, six German astronomers assembled at the little town of Lilienthal, determined to make a serious effort to track down the missing planet. These 'celestial police', as they were nicknamed, elected the hard-working Schröter president, with another eminent astronomer, Baron von Zach, as secretary; and between them they worked out a scheme according to which each observer would be responsible for one particular part of the ecliptic, where the planet, if it existed at all, would probably be found.

Naturally, a plan of this sort takes some time to bring into working order; and before Schröter's 'police' were fully organized, they had been forestalled. Piazzi, director of the Sicilian observatory of Palermo, was compiling a star catalogue, and on January 1, 1801 – the first day of the new century – he picked up a starlike object which behaved in a most unstarlike manner. It moved appreciably from night to night. Piazzi thought at first that it was a tail-less comet, but went so far as to write to von Zach; evidently he had his suspicions. By the time that von Zach received the letter, the moving body had been lost in the rays of the Sun.

Fortunately, however, Piazzi had made enough observations to enable an orbit to be worked out, and it was soon clear that the object was not a comet at all, but a planet. Exactly a year after its original discovery, it was re-detected, and was named Ceres, in honour of the patron goddess of Sicily. It was found to have a mean distance of 27·7 on the Bode scale, which corresponded most satisfactorily to the predicted 28. The Solar System was again complete.

Yet Ceres turned out to be a miniature world, only about 500 miles across, and seemed hardly worthy to be ranked with the major planets. Significantly, the 'celestial police' continued their efforts, and it seems to have come as no surprise when one of them, Dr. Olbers, picked up a second small planet in March 1802. This new member of the Sun's family was given the name of Pallas; it was so like Ceres in size and orbit that Olbers suggested that the two had been formed from one larger planet which had met with some sort of accident. The idea was attractive; if there were two fragments, there might be others – and two more planets were duly found within a few years. Juno was



A. 1921, Jan. 6 B. 1921, Jan. 10

FIG. 18. Ceres: (A) 1921, Jan. 6; (B) 1921, Jan. 10 (3-inch refractor, ×80; H. P. Wilkins)

discovered by Harding at Lilienthal in 1804, and Vesta by Olbers in 1807.

Juno and Vesta much resembled the two senior members of the planet swarm, and the four became generally known as the 'Asteroids', or Minor Planets. No more seemed to be forthcoming, and the 'celestial police' disbanded in 1815, probably because of the death of Schröter.

Nothing further was done until 1830, when a Prussian amateur named Hencke took up the problem and began a systematic search for new asteroids. Alone and unaided, he worked away for fifteen years, and at last had his reward – a new minor planet,

now named Astræa, circling the Sun at an average distance slightly greater than Vesta's, slightly less than Juno's. However, Astræa was considerably fainter than the first four, with an estimated diameter of only about 60 miles.

Even the enthusiastic Hencke would have been surprised to learn that his discovery was a mere prelude to thousands more. He himself found another asteroid, Hebe, in 1847; in the same year Hind, in London, discovered Iris and Flora; 1848 and 1849 yielded one asteroid each, but since then few years have produced fewer than two. By 1870, the total number was 109, and twenty years later this had grown to 300. Then, in 1891, Max Wolf of Heidelberg introduced a new method of asteroid detection which caused an even quicker rate of increase.

Wolf's method was a photographic one. If a camera is adjusted to follow the ordinary stars in their daily motion across the sky, a time exposure will show up an asteroid as a streak across the plate – because an asteroid moves individually among the stars. If I set my camera to photograph a garden, and then walk in front of the lens during the time-exposure, I shall appear as a blur, because I have moved. The asteroid will not blur, because it is a hard, sharp point of light; but its movement will certainly betray it.

The Wolf method was almost embarrassingly successful, and the numbers of known asteroids increased by leaps and bounds. Wolf himself was responsible for adding over a hundred, and by 1950, 1,500 small planets had had their orbits satisfactorily worked out, while at least a thousand more had been found on the plates without having been under observation for long enough to have their paths computed.

It cannot be said that the asteroids proved to be popular members of the Solar System. Photographic plates exposed for quite different reasons were often found to be swarming with short tracks; and the irritating little planets complicated star-counts and similar work to such an extent that German astronomers, who nobly established a computing centre to try to keep pace with them, started referring to the 'Kleineplanetenplage' (minor planet pest). Another observer, this time an American, christened them 'vermin of the skies'.

Another difficulty was to find names for them. The early

FIG. 19. Sizes of asteroids, compared with England, Scotland, Ireland and Wales

asteroids were dignified with mythological names such as Psyche, Thetis, Proserpine and Circe; but as time went on, and the numbers grew and grew, the supply of mythological names began to give out. Many of the later names are odd, to say the least of it. For instance, No. 724 is named Hapag, the initials of a German navigation line, Hamburg Amerika Paketfahrt Aktien Gessellschaft; No. 694 is Ekard, the name 'Drake' spelt backwards (it was christened by two members of Drake University, Iowa); and No. 692 seems to have acquired the baffling name of Hippodamia, which sounds imposing but which actually means nothing at all.

The normal asteroids are, perhaps, the least notable of all the heavenly bodies. Few are as much as 100 miles across, and all are airless and lifeless – the smaller ones mere pieces of rock, probably not even spherical. One or two have unusual paths; Pallas' is tilted at an angle of 35°, and No. 279, Thule, is unusually remote, circling the Sun at an average distance of almost 400 million miles, as against the 225 million of Ceres. Only one, Vesta, is ever bright enough to be seen without a telescope – and then only if one knows just where to look for it.

Towards the end of the last century, it was noticed that the asteroids tended to fall into groups, and this was held to be due to the tremendous disturbing influence of the giant planet Jupiter. However, all the normal asteroids kept strictly to the gap between the orbits of Jupiter and Mars, and no one was prepared for the peculiar behaviour of No. 433, Eros, which was discovered in 1898 by Dr. Witt, at Berlin.

Eros is one of the smaller members of the asteroid swarm, and is never a conspicuous object; its oddity lies in the fact that it comes well inside the main group. Its orbit is eccentric, so that the aphelion point lies well beyond Mars, but at perihelion it moves closer to the Sun than Mars ever gets; consequently, it can at times approach the Earth, and its minimum distance from us is only 14 million miles. Close approaches are rare, and not until 1975 will it come as close as this; but in 1931 it passed within 17 million miles of us, and was a comparatively bright telescopic object.

When at its nearest, Eros is so close to us that its distance can be measured very accurately, and this gives us a key to the whole scale of the Solar System – in particular, to the distance of the

Earth from the Sun. Hundreds of photographs taken at the approach of 1931 enabled the Astronomer Royal, Sir Harold Spencer Jones, to arrive at the figure of 93,003,000 miles for the length of the 'astronomical unit' (Earth-Sun distance). Eros, at least, has its uses, and compensates in some measure for its irritating fellows.

Eros is unusual in itself, as well as in its movements. In 1931 it was found that the light sometimes varied, in an average period of about 5 hours. Since no planet or asteroid has any light of its own, the only explanation was that Eros is irregular in shape; and this was confirmed by van den Bos, who saw the asteroid oval at times. It has been calculated that Eros is 15 miles long

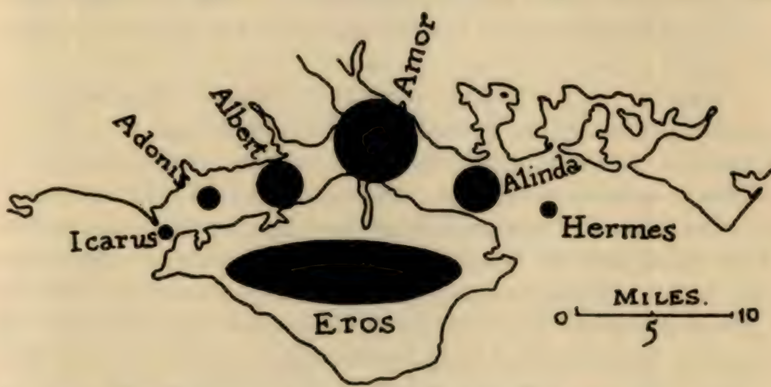


Fig. 20. Sizes of asteroids, compared with the Isle of Wight. The exact size of Eros is uncertain

and about 4 wide, spinning about its smaller axis rather in the manner of a celestial sausage impaled upon a stick! The diagram (Fig. 20) shows Eros compared in size to the Isle of Wight, with several other interesting asteroids drawn in to scale.

For some time Eros was thought to be unique, but in 1911 Palisa, at Vienna, discovered a tiny asteroid which can at times approach us within 20 million miles, though its orbit is so eccentric that its aphelion distance is almost as great as that of the distant Thule. It was numbered 719, and named Albert. Unfortunately it is only 3 miles across, and after its brief visit in 1911 it vanished into the distance; so far it has not been re-discovered. A tiny body such as Albert is susceptible to even the smallest

perturbations, and its recovery is bound to be largely a matter of luck. We simply cannot work out its orbit accurately enough to tell just where it will reappear.

No. 887 Alinda, discovered by Wolf in 1918, and No. 1036 Ganymede,[1] found by Baade in 1924, are other asteroids with orbits similar to that of Albert; but all these, Eros included, were outdone by Amor and Apollo, the two 'earth-grazers' of 1932.

No. 1221 Amor, found by the Belgian astronomer Delporte, is a full five miles across – about the size of Deimos, Mars' outer moon, and considerably larger than Albert or Alinda. It came within 10 million miles of the Earth, and was under observation for long enough to enable the mathematicians to work out a really reliable orbit. Amor's 'year' is 975 of our days, and after it had been twice round the Sun unseen it was picked up again in 1940.

However, Amor's reign as the Earth's nearest visitor was brief. Apollo, discovered by Reinmuth at Heidelberg later in 1932, approached to within 7 million miles, and at its perihelion is a mere 59 million miles from the Sun – closer in than the Earth or even Venus. Consequently, it can play some strange tricks. Like Mars and the outer planets, it is best seen at opposition; but it can also pass through inferior conjunction, and actually transit the solar disk, though it is so small that it could not possibly be observed during transit. Unfortunately Apollo, like Albert, has been lost, and today we do not know where it is.

Adonis, found by Delporte in 1936, veered past us at only 1½ million miles, and at perihelion approaches the orbit of Mercury; but in 1937 Reinmuth discovered an even more interesting earth-grazer, subsequently named Hermes. Even smaller than Adonis, with an estimated diameter of only a mile, it brushed by us at only 485,000 miles, a distance barely double that of the Moon. It is possible for it to come still closer, actually passing between Earth and Moon.

Needless to say, astronomers were not in the least alarmed by this celestial visitor. Hermes may have been very close in the astronomical sense, but we were in no danger of a collision; in

[1] This is a most unfortunate name, as Ganymede is also the name of the third satellite of Jupiter. No. 1036 is rather larger than the other members of its group, and seems to be about 20 miles in diameter.

fact, the chances of our being hit by an 'earth-grazer' are millions to one against. If we reduce the Earth in scale to a 12-inch globe, Hermes can be compared to a speck of dust passing several feet away.

It is true, of course, that if a collision really did take place, the damage would be widespread. In 1908 a meteorite with a diameter of about 1,000 feet hit Siberia, devastating an area of hundreds of square miles; and there is no difference, except in name, between a large meteorite and a small asteroid. When the Hermes story was made known, in January 1938, the Press seized upon it with avidity, and the headlines of national papers on January 10 were highly sensational. "World Disaster Missed by Five Hours", was one example. "Scientists Watch a Planet Hurtling Earthward."[1] However, Hermes, interesting though it is, was certainly no threat. At the moment it is lost, but it may be rediscovered one day.

Mars, closer to the main swarm than we are, also has its visitors. No. 1009, Sirene, can pass within five million miles of the Red Planet, and doubtless smaller asteroids approach even closer.

For many years Thule was regarded as the outermost member of the asteroid swarm, but in 1908 Max Wolf detected No. 588 Achilles, which was obviously more remote. In fact, it appeared to move in almost the same orbit as mighty Jupiter. Further investigations showed that this was indeed the case, unlikely though it appeared at first sight.

Achilles is 150 miles across. This is on the large side for an asteroid, but even so it is utterly insignificant when compared with Jupiter. It survives by virtue of its position. It really does move more or less in Jupiter's orbit, but keeps well ahead of the giant planet, and therefore out of harm's way. Jupiter and Achilles may be compared to two spots of paint on the rim of a turning wheel.

Shortly after Achilles was discovered, another asteroid was found also moving in Jupiter's orbit, but on the far side from Achilles. It was named Patroclus, and more recently discovered members of the group have been allotted other Homeric names,

[1] To add insult to injury, another reputable daily paper described Dr. Reinmuth, the eminent discoverer of many asteroids, as "a German *astrologer*".

so that they are known collectively as the Trojans. Achilles has six known companions, Patroclus four (Fig. 21). Unfortunately the Greeks and Trojans are mixed up, and Achilles and Hector actually find themselves near neighbours.

It was thought that the Trojans marked the extreme outer limit of the asteroid swarm, but this did not prove to be the case. Hidalgo, discovered by Baade in 1920, is not a Trojan, but has a most extraordinary orbit which carries it from just outside Mars right out to Saturn. Its 'year' is as long as 14 of ours, and its

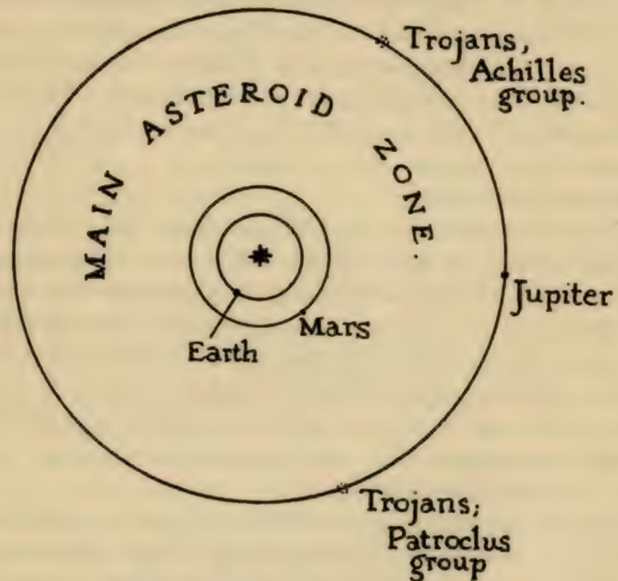


Fig. 21. The Trojan asteroids

orbit is so eccentric that it moves more like a comet than an asteroid. In fact, its nature was for some time suspect. It was carefully photographed with the 100-inch reflector at Mount Wilson, but always showed up as a hard, sharp point of light, devoid of any trace of the fuzziness which betrays a comet. Rather reluctantly, we are bound to include Hidalgo in the asteroid family, though with the inner feeling that it is something of a black sheep!

The movements of the more normal asteroids are not without

their interest. As we have seen, the minor planets tend to fall into well-defined groups, and five of these groups contain large numbers of asteroids whose orbits are so alike that they seem certainly to have had a common origin. This brings us back to Olbers' theory of a disrupted planet which originally circled the Sun between Mars and Jupiter.

For many years Olbers' theory was in disfavour, but now the pendulum seems to be swinging back to it. According to Dr. Oort, of Holland, the original planet exploded; the fragments thrown into nearly circular orbits became asteroids and meteor swarms, while those with more elliptical orbits were so violently pulled by Jupiter and the other giant planets that some were driven out of the Solar System altogether, while the remainder formed an outer cloud of comets.

In this case, the asteroids must originally have possessed gaseous envelopes; but their low escape velocities make them incapable of holding on to gas of any kind, and it would take them only a short while to lose every trace of atmosphere. We know that none of the present asteroids, even Ceres, can retain any vestige of air or moisture, and that consequently any form of life, as we know it, is totally out of the question.

Before leaving these miniature worlds, let us say something about perhaps the most remarkable of all—Icarus, discovered by Dr. Baade in June, 1949.

When discovered, it was about 8,000,000 miles away, and as it can never come closer than 4,000,000 it is not an 'earth-grazer' in the sense that Adonis and Hermes are; but it is unique inasmuch that at perihelion it is actually a mere 19 million miles from the solar flames, far closer even than Mercury. At aphelion, it recedes to a distance of 183 million miles, well beyond Mars. In addition to being very eccentric, the orbit is also sharply tilted, so that its path never actually intersects that of the Earth.

Icarus, a tiny world only a mile or so across, was named after the youth who is said to have escaped from Crete with the aid of artificial wings, and flew so close to the Sun that the wax of his wings melted and he fell to his death in the sea. The name is apt; Icarus must bid fair for the title of the most uncomfortable world in the entire Solar System. What shall we see if we remain on it for a whole Icarian 'year', some 400 terrestrial days?

If we land in 'winter', the temperature will be terribly low, with the Sun small and shrunken in the star-spangled sky; needless to say there is no trace of air, and the gravitational pull of Icarus itself is so small that it cannot be felt. Three hundred million miles away, we can see Jupiter, majestic and remote; there are other asteroids, too, but we are some distance from the main swarm – the highly-tilted orbit of Icarus will never take us through the thickest part of the crowd.

Time passes, and gradually we approach the Sun. Mars is not far off now, glowing in the sky like a reddish-ochre ball; we can see the dark vegetation areas, the polar caps, and even the two moonlets, Phobos and Deimos. But our attention is soon turned to the Earth, a beautiful globe of green and blue, streaked with whitish clouds. About four months after our arrival on Icarus, we are close to our own world – less than ten million miles away, so that the continents and oceans are plain, as well as the chief craters and mountain ranges of the Moon.

But we are moving faster and faster as we close in towards the Sun. The temperature is rising with alarming rapidity; from the bitterness of outer space, we are approaching the central furnace. Venus is passed; we can see the scorched, ever-sunlit face of Mercury, and seven months after our arrival on Icarus will see us at perihelion, only 19 million miles away from the solar surface.

It is fortunate that we are travelling only in imagination, for no human eye could stand up to the light and heat for even the fraction of a second. The Sun glares upon us with a fury beyond man's understanding. It blazes from the black Icarian sky, a blinding globe of fire that scorches and sears, until the surface of the Sun-turned side of Icarus is so hot that it glows dull red; we see now why the rocks of the tiny world are so crumbled and broken – the alternate baking and freezing has broken them down. Gradually we swing round the glaring orb; the heat dies down, the surface rocks cease to glow, and Icarus moves away from the Sun back into the depths of the Solar System, once more to experience the winter bitterness of interplanetary cold.

In the far future, when we have pushed our frontiers beyond the Earth, some of the larger and more conventional asteroids may prove of value to us. Their low escape velocities may make them suitable for use as space-stations, and perhaps even the

'space-beacons' of 1954 storytellers may not be so far removed from fact. However, it is safe to say that Icarus, scorched and frozen during each revolution round the Sun, will be left severely alone. It is the Devil's Island of the Solar System.

To the ordinary observer, the asteroids are of little interest; they show no measurable disks, and even when found they seem hardly worth the trouble spent on the search. However, they are not without their value; and the strange orbits of Eros, Achilles, Hidalgo, Icarus and their kind show us that the anonymous American observer was unjust in dismissing them all as mere 'vermin of the skies'.

CHAPTER II

Jupiter

Far beyond the main asteroid swarm, nearly five hundred million miles from the Sun, circles mighty Jupiter, giant of the Solar System. The ancients named it after the King of the Gods, and the name is indeed appropriate, as Jupiter is more than twice as massive as all the other planets put together. Its great globe could contain thirteen hundred bodies the size of the Earth.

Even though it is so remote, Jupiter appears as a splendid

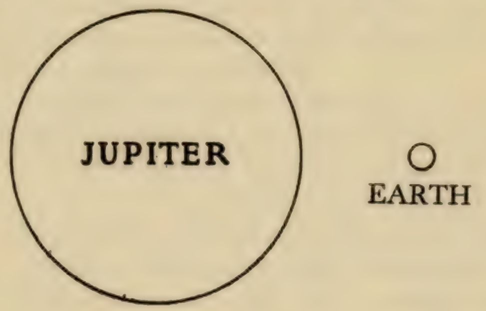


Fig. 22. Comparative sizes of Jupiter and the Earth

object in our skies. It is brighter than any other planet apart from Venus and (very occasionally) Mars; F. M. Holborn has recorded that at times it is bright enough to cast a shadow. It moves very slowly compared with the Earth, so that it comes to opposition at intervals of only slightly over a year. Jupiter's own 'year' is almost twelve times as long as ours, so that no being with a life-span comparable to our own would survive to celebrate his ninth birthday!

Jupiter's equatorial diameter is 88,700 miles, over eleven times that of the Earth, but even a small telescope will show that there is considerable polar flattening. The polar diameter is, in fact, only 83,800 miles. There is a simple explanation of this. Although

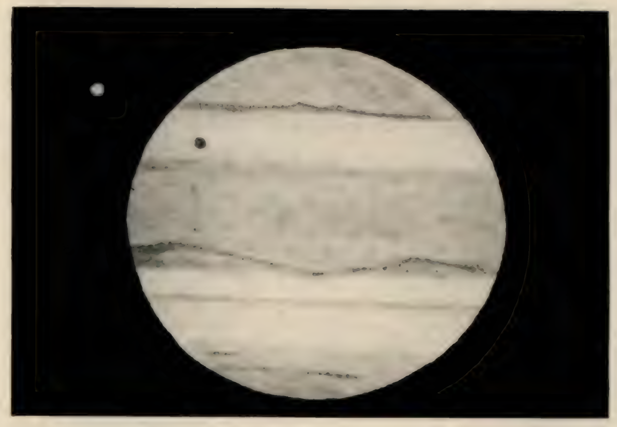


Plate XIX. Shadow transit of Io (1951, Oct. 19, 22h. 50m., $12\frac{1}{2}$-inch refl. $\times$200, seeing moderate, Patrick Moore)

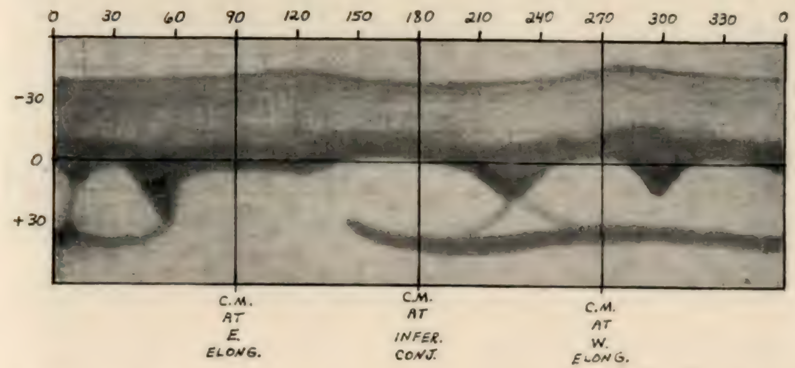


Plate XX. Map of Ganymede by E. J. Reese (based on observations by Cave, Cragg, Sandner, Oberndorfer, Haas, Brinckman)

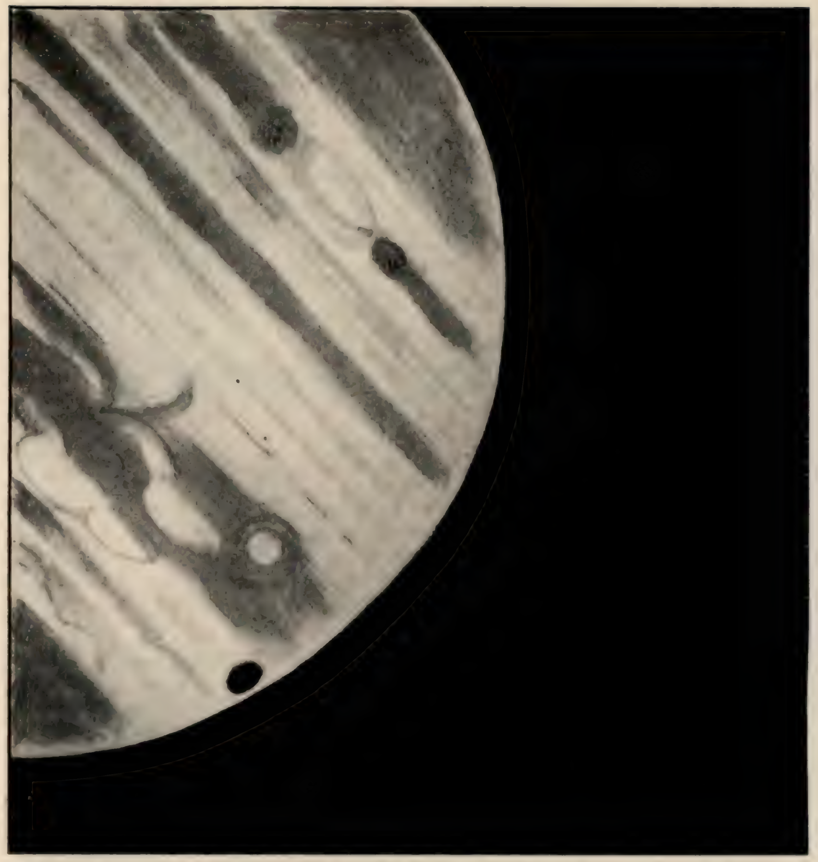


PLATE XXI. Jupiter. Transit of Io and shadow (1951, Oct. 19, 15¼-inch refl. ×300, H. P. Wilkins)

Jupiter is the largest planet in the Solar System, it has the shortest axial rotation period – less than 10 terrestrial hours – and so is spinning at tremendous rate; particles at the equator are whirling round at no less than 28,000 m.p.h. Centrifugal force is so strong in the equatorial zone that it causes the whole zone to bulge out, forcing the planet into the shape of a somewhat squashed orange. There is a similar effect for our own world, but with us the difference between the equatorial and polar diameters amounts to less than 30 miles, as against 5,000 miles for Jupiter.

This marked flattening shows that Jupiter cannot be solid in the sense that the four inner planets are. This is confirmed at once by telescopic observation. As with Venus, we look down not upon a solid surface, with mountains, plateaux and deserts, but upon a sea of clouds – shifting and changing unceasingly. However, there are important differences between the clouds of Venus and those of Jupiter. On Venus, the cloud-layer hides a solid body which makes up the overwhelming bulk of the planet; deep though it is, Venus' air-mantle is no thicker, relatively, than the shell to an egg. Jupiter's 'atmosphere' is far deeper in proportion. Indeed, it is by no means certain that the planet has a proper solid surface at all.

In a way, it is misleading to speak of the outer cloud-layers of Jupiter as an 'atmosphere'. More accurately, it is part of the body of the planet, for Jupiter is not so heavy as might be imagined from its vast size. Its average density is only one-quarter of that of the Earth, and only 1⅓ times as great as water; and though it has a powerful gravitational pull, and exerts marked influence upon asteroids, comets and even other planets, it is only 317 times as massive as the Earth. It would thus take over a thousand Jupiters to make one body as massive as the Sun.

The Jovian clouds are quite unlike those of either Venus or the Earth. Both the two gases which seem to be present there in vast quantities are most obnoxious from our point of view. One of them is ammonia, familiar to most people (ordinary household ammonia consists of the gas dissolved in water), and the other is methane, known commonly as marshgas and to miners as the dreaded 'fire-damp'. Methane has been responsible for a good many fatal pit accidents in the past, since under terrestrial conditions (*i.e.* mixed with oxygen) it is dangerously explosive; and

it, like ammonia, has a strong, unpleasant odour. If the bottom of a long-stagnant pond is stirred with a long pole, the bubbles which rise to the surface are made up largely of methane. Altogether, the atmosphere of Jupiter seems to be offensive, to put it mildly.

However, the real significance of the ammonia and methane is that both are hydrogen compounds. Ammonia is made up of hydrogen and nitrogen; methane, of hydrogen and carbon. Hydrogen is easily the most abundant element in the universe, and undoubtedly both Jupiter and the Earth possessed a great deal of it in their extreme youth. The Earth's hydrogen leaked away; Jupiter's, held down by the crushing gravitational pull, did not,

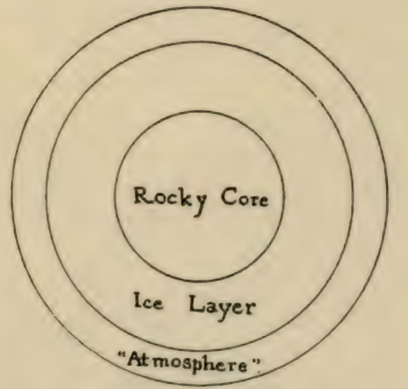


FIG. 23. Wildt's model of Jupiter

and much of the gas combined with other elements to form the dense, poisonous, ammonia-methane atmosphere of today.

Hydrogen in the pure state is very shy of showing itself in our spectroscopes, but there is probably a great deal of it on Jupiter. Oxygen gas is lacking. It seems probable that most of the original oxygen has combined with yet more hydrogen to form water, and deep down below the outer gas there may well be a thick ocean of ice.

As we cannot see below the uppermost layers of Jupiter's gas-clouds, all we can do is to form a picture of the structure of the planet by indirect reasoning. Dr. Rupert Wildt, of the United States, considers that the general structure is as shown in Fig. 23; a rocky, metallic core 37,000 miles in diameter, overlaid by an ice layer 17,000 miles thick, which is in turn overlaid by the ammonia-methane-hydrogen atmosphere, which has a depth of 8,000 miles. This theory was generally accepted until very recently.

If Wildt's model is correct, strange things must be happening at the bottom of the gas-layer. The pressure must be crushing—far beyond our experience—and although still gaseous in the technical sense, the material must tend to behave much more like a solid. However, it is difficult to be at all certain just what the conditions are, since we do not know much about the temperature gradient. The surface temperature is known; it is about −200° F., which is below the freezing point of ammonia, so that the clouds themselves seem to consist of small ammonia crystals suspended in the atmosphere—much as ice-crystals are held in terrestrial clouds. (We do observe ammonia gas as well, presumably vapour which has sublimed from the solid crystals.) Unfortunately this gives us no clue as to the temperatures lower down.

Until the present century, it was commonly believed that Jupiter had some light of its own, and did not rely wholly upon the Sun; but this is definitely not the case. The surface temperature is just about what would be expected if the surface was warmed only by the Sun; and even if the centre of Jupiter is hot, very little heat can percolate through to the upper clouds. Dr. W. R. Ramsey considers that the temperature at the centre is 10,000° C. or less, which is not enough to have much effect upon the outer layers, particularly if the temperature gradient is fairly sharp.

However, Dr. Ramsey does not support the Wildt rock-ice-gas model. In his opinion Jupiter consists mainly of hydrogen, and this seems eminently reasonable when we bear in mind the great preponderance of hydrogen in the Sun and stars. If hydrogen is responsible for 80 per cent. of Jupiter's mass, there will be no fundamental difference between the centre and the outer layers, except that the terrific pressure near the centre will compress the hydrogen gas so much that it will actually start to behave like a metal, not like a gas at all.

At the moment, it is impossible to decide definitely between

the Wildt and Ramsey models; but one of them is probably correct. What we do know, for certain, is that Jupiter is built upon a pattern very different from that of the Earth; it is clear that any form of life as we know it is impossible there.

Another fundamental difference between the clouds of Venus and those of Jupiter is that the Cytherean clouds show little or no detail, apart from hazy, nebulous patches, whereas Jupiter's cloud-layers abound in detail. This detail is constantly changing, and is easy to observe even in a small instrument, so that the Giant Planet is without doubt one of the most fascinating of all telescopic objects.

The most conspicuous markings on the yellowish, flattened

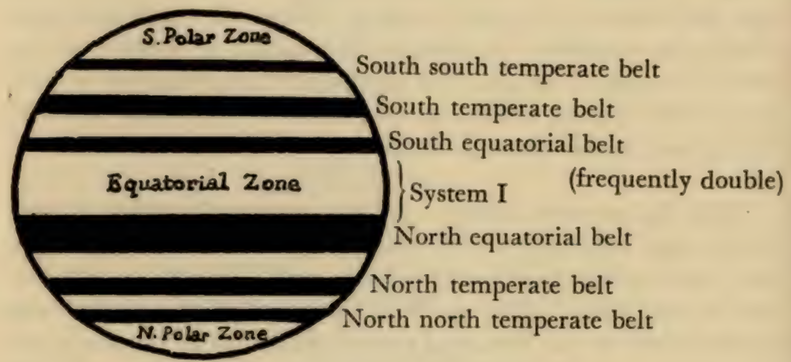


FIG. 24. The belts and zones of Jupiter

disk are the cloud belts. There are a number of these, running straight across the planet, and all drawings and photographs show them prominently.

At a casual glance the belts appear as dark, regular lines, but close examination shows that they are far from regular. They reveal considerable structure; brighter and fainter portions, knots, divisions, spots and notches. A typical drawing of the main belt, the North Equatorial, is shown in Plate XII.

Although the North Equatorial is generally the most prominent of the belts, there are frequent alterations in relative intensity. For instance, the South Temperate belt (see Fig. 24) was very prominent in the autumn of 1952, with the South Equatorial

relatively obscure; in early December the South Temperate faded abruptly, while the South Equatorial leaped into prominence, almost equalling its northern counterpart.

Details in the belts often persist for days on end, and consequently it is an easy matter to obtain the axial revolution period of Jupiter. It turns out to be very short indeed, only 9¾ hours or so; but it is difficult to give an exact value, as different zones of the planet spin at different rates. The equatorial region, bounded by the north edge of the South Equatorial belt and the south edge of the North Equatorial, is known as System I, and has a period of about 9 hours 50 minutes; the rest of the planet (System II) has a period about five minutes longer, though various features seem to have their own particular rates of rotation.

This provides additional proof, if it were needed, that we are looking at clouds and not at a solid surface. The exact determination of the rotation periods for various zones and special features is an important branch of modern Jovian study, and the best work so far has been done by the Jupiter Section of the British Astronomical Association, directed for many years by the Rev. T. E. R. Phillips and now by Dr. A. F. O'D. Alexander.

Spots are very common on Jupiter, but one of them, the Great Red Spot, is of particular interest owing to its long life. In fact, it has persisted for so many years that we may almost regard it as a semi-permanent feature. It is well shown in the Palomar photograph (Plate X), and can be found lying in its peculiar 'hollow' south of the South Equatorial Belt.

It first became prominent in 1878, developing from a pale pink, oval object into a brick-red area 30,000 miles long by 7,000 wide – so that its surface area was equal to that of the Earth. Naturally enough, it attracted a good deal of attention, and was traced with fair certainty on various earlier drawings. Schwabe, a German observer best remembered for his discovery of the sunspot cycle, had drawn it in 1831, and indications of it were found on a drawing made by Hooke as long ago as 1664. If we accept the Hooke drawing, the Spot has persisted for at least 250 years, and must be something more than a mere 'cloud'.

The startling red colour did not last for more than a few years, and since 1890 the Spot has faded considerably, sometimes being recognizable only because of its characteristic 'hollow'. It

revives at intervals, however – it became prominent again for a while in 1936 – and some observers still call it pinkish at times, though personally I have never seen it anything but grey.

It has been suggested that the Spot is the top of a gigantic volcano, poking out through the dense cloud-layer. Unfortunately for this theory, it is not fixed in position. It drifts about, within certain limits of longitude, and has been known to shift some 20,000 miles to either side of its mean position. It may well be a solid body of some sort floating in the atmosphere, and this idea would also account for its variations in prominence, since when lower down – and hence covered by more of the atmospheric gas – it would naturally appear less noticeable.

The fading of the Red Spot may be bound up with a much more widespread loss of colour on Jupiter. Vivid hues have been reported in the past; reds, browns and carmines used to be described, and the belt areas, in particular, were rich in colour. The present situation is rather different. No colours are conspicuous, and there can be little doubt that there has been a general fading over the past twenty years. It is most unlikely that there has been any fundamental change in the composition of the belts and spots, so that once again it seems probable that the overlying gas has increased in depth. If this is the case, the loss of colour may be only temporary, and the vivid hues may return at any moment. Wildt interprets the colours on Jupiter as due to various solutions of metallic sodium in liquid or solid ammonia.

Most of the other Jovian features are short-lived, lasting for a few months at most, though now and then objects of particular interest are seen. Between 1930 and 1934, for instance, the B.A.A. observers recorded some strange spots which moved in a 'circulating' current of the south temperate zone; and there are also occasional violent upheavals in the region of the South Equatorial belt, one of which occurred as lately as 1949.

One other feature of great persistence should be mentioned. This is the South Tropical Disturbance, a dark area in the Red Spot zone which has been seen almost continuously since 1901. It is slightly closer to the equator than the Spot is, and has a slightly shorter rotation period, so that every two or three years it actually catches the Spot up and passes it. While this is going

on, there is a marked interaction between the Disturbance and the Spot; the Disturbance tends to accelerate, and as it passes by it seems to drag the Spot with it for several thousands of miles. When the Disturbance has gone on its way, the Spot drifts slowly back to its original position.

We can observe the behaviour of the surface clouds, and we can even find out a good deal about their composition, but we have to admit that we have no real idea of how the belts and spots arise. Great volcanic upheavals have been suggested, but until we know more about the inner structure of the planet it is really pointless to speculate.

It does, at least, seem certain that we shall never be able to land on Jupiter. Apart from the coldness, the poisonous gas-mantle and the generally unfavourable conditions, the gravitational pull renders all Jovian expeditions totally out of the question. Escape velocity is 37 miles a second, so that the task of taking off again, once we had landed, would be a hopeless one; moreover, a human being would feel alarmingly heavy – a man who weighed 14 stone on Earth would weigh 36 on Jupiter. If we are to visit the Jovian system at all, we must resign ourselves to keeping well clear of the giant planet itself, and making our investigations from a base upon one of the satellites.

When Galileo first turned his newly-made telescope to the heavens, in 1609, he saw that Jupiter was attended by four star-like objects that soon proved to be satellites. Simon Marius, who observed them at about the same time, christened them Io, Europa, Ganymede and Callisto; and though these names were not accepted until recently, they have now come into general use.

All four satellites can be seen with any small telescope, and there are plenty of records of naked-eye observations of them, so that obviously they must be fairly large. The most recent values for their diameters are 2,310 miles for Io, 1,950 for Europa, 3,200 for Ganymede and 3,220 for Callisto, so that only Europa is smaller than our Moon; both Ganymede and Callisto are appreciably larger than the planet Mercury, though not so massive.

The orbits of all four 'Galileans' lie in much the same plane, and telescopically they appear to keep in a straight line. There

are various interesting phenomena connected with them. They may be eclipsed by Jupiter's shadow, they may transit the disk or be occulted behind it, and their shadows may be seen passing across the Jovian disk even while the satellite itself is still clear of transit. All these phenomena are forecast in publications such as the B.A.A. Handbook, and with a little practice it is quite easy to tell one satellite from another.

Io, closest in of the four, is slightly more massive than our Moon, and has an escape velocity of $1\frac{1}{2}$ miles a second. It is 262,000 miles from Jupiter, but the tremendous gravitational pull whirls it right round the planet in only 1 day $18\frac{1}{2}$ hours, and it is believed – though without definite proof – that the axial rotation, the Ionian 'day', is of equal length. If this is so, Io always keeps the same face to Jupiter, much as the Moon behaves with respect to the Earth or, for that matter, Mercury with respect to the Sun. There is no mystery about this. Tidal friction is responsible, and

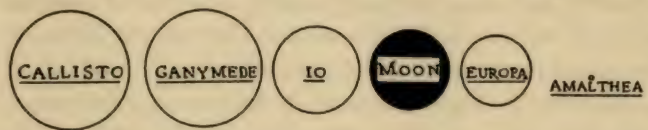


FIG. 25. Sizes of five of Jupiter's satellites, compared with the Moon. The remaining seven satellites are too small to be shown on this scale

it is highly probable that most of the satellites of the giant planets behave in the same way.

Io is rather denser than the Moon, so that it is undoubtedly a rocky world, and Kuiper is of the opinion that "an excess of metals" is probably present in it. It is a good reflector of sunlight, and Kuiper considers that this may be due to a surface cover of oxide smoke. Despite the smallness of its apparent disk, markings can be seen with large telescopes, and a brightish equatorial zone seems to be well established.

An interesting problem in connection with Io is that of its colour. Hertzsprung, in 1911, stated that it was strongly orange, and many later observers have agreed; but to me it never appears anything but white, or at the most faintly tinged with yellow – and this was also the opinion of other B.A.A. observers in 1952. Moreover, Io sometimes shows peculiar fluctuations in brilliancy, and I once saw it brighten up strikingly in the space of two

hours for no apparent reason. A tenuous atmospheric mantle may exist, but has not, so far, been detected.

Europa, the second satellite, is smaller and less massive than Io; but it appears almost as bright, so that it is even more efficient as a reflector of sunlight. Indeed, it seems to reflect about 75 per cent. of the light falling upon it, and its surface must therefore be coated with a substance which glitters and sparkles in the pale radiance of the far-away Sun. An interesting result of this is that very little heat can be absorbed, and probably the surface of Europa is unusually cold, even for the chilly Jovian system. Surface markings have been seen, and Europa appears to have a darkish 'equator' with brighter 'poles'. It is white in colour, and like Io is rather unusually dense.

Ganymede, third and brightest of the Galileans, is strangely lacking in mass for its size. It seems to be a planet in dimensions, but a satellite in weight; certainly it is more massive than the Moon, but even so its escape velocity is only $1\frac{3}{4}$ miles a second.

Telescopically, Ganymede shows a distinctly yellowish disk, upon which markings can be seen without much difficulty. Charts have been drawn by various observers – in particular by Dr. Lyot and his colleagues at the Pic du Midi – but the most modern map is that of E. J. Reese, reproduced here. Superficially, the appearance is rather like that of Mars, and the dark equatorial zone, with its wedge-shaped markings, has a vaguely familiar look. However, not even the most ardent supporter of "life on the other worlds" would attribute the Ganymedan dark areas to vegetation. Apart from the bitter cold, Ganymede is almost or quite airless. It should be capable of holding on to an atmosphere of sorts, but up to the present results have been negative, and if there is an air-mantle it must be very tenuous.

The low density, less than twice that of water, remains a problem. It has been suggested that the globe consists of a rocky core coated with ice or even solid carbon dioxide, but the general surface features do not give any such impression.

Callisto, the outermost of the Galileans, is in many ways the most interesting of the four, since it is both the largest and the least massive. Recent measures of its diameter make it slightly larger than Ganymede and much larger than Mercury; yet it has only half the mass of the Moon. Its density is only just

greater than that of water, and the escape velocity is less than a mile a second. Moreover, it is a very poor reflector of light, and its colour has been described variously as bluish, ruddy, bluish-grey and violet – my own opinion being that the nearest one can get to a verbal description is 'faint reddish-violet'. Obviously, there is something very odd about Callisto's constitution.

The disk is much duller than that of Ganymede, and consequently much more difficult to observe. Surface details have been seen, but the only established features are a darkish equatorial zone and a brighter 'cap' near the probable position of the south pole. (Callisto is over a million miles from Jupiter, and has a period of 16½ days, but like its companions it too seems to keep one face turned respectfully towards its primary.) The curiously low density is still unaccounted for. Some astronomers have suggested that Callisto is a sort of a celestial snowball, made up of icy, loosely-packed materials; but on the whole it is more probably composed of a core of light rock – pumice, perhaps – overlaid with a layer of ice. Owing to the low escape velocity, it is unlikely to have retained any appreciable atmosphere.

The transits, shadow transits, eclipses and occultations of the four Galileans are fascinating to watch, and each satellite has its own way of behaving. During transit, for instance, Io and Europa are usually hard to find except when passing across a dark belt or when close to Jupiter's limb, whereas the less reflective Ganymede and Callisto show up as dark spots against the brighter background. The shadows are usually easy to track. A typical drawing, made with my 12½-inch reflector, is shown in Plate XIX; the black dot on the disk is the shadow of Io, though Io itself is clear of Jupiter. The satellite had in fact emerged from transit ten minutes earlier, appearing as a brilliant, gleaming spot as it moved off the body of the giant planet.

Sometimes the satellites themselves are difficult to tell from their shadows, particularly in the cases of Ganymede and Callisto. In October 1950, Barker once recorded Ganymede in transit as "a brownish disk, close to a circular brown spot of equal size", and had to do some calculations, with the aid of the *Nautical Almanac* tables, to find out which was which. Moreover, unusual things are sometimes seen. Io behaved strangely in August 1951; during the transit of August 3 it was unusually bright, during the transit of August 24 unusually dark. This might be attributed to different parts of the surface being turned towards us, but such an idea does not fit in well with the strong probability that Io keeps the same hemisphere turned permanently towards Jupiter.

An even more interesting observation was made on 1951 December 10 by F. M. Bateson, in New Zealand. At 6 hours G.M.T., Io had just completed a transit, and was clear of the disk; the shadow was still visible, half-way between the central meridian and the Jovian limb. The shadow appeared perfectly round and black, as is normal, but a second shadow – round and greyish – could be seen just south of it, following the true shadow. Bateson followed this second shadow until the pair had almost reached the limb, and it is unlikely that he was deceived by any instrumental defects or vibration, as was suggested by some authorities when his observation was published. Possibly the phenomenon was due to Io's shadow falling upon two reflecting layers of the Jovian atmosphere.

An interesting historical fact is that the eclipses of Jupiter's satellites led to the first determination of the velocity of light. In 1675 a noted Danish astronomer, Olaus Römer, noted that the predicted eclipse times were not always accurate; when Jupiter was relatively close to us, near opposition, the eclipses were early, whereas when Jupiter was more remote they were late. Römer realized that this must be because the light had further to travel when Jupiter was distant. After elaborate calculations, he deduced a value for the velocity of light which was remarkably close to the true value of about 186,000 miles a second.

The eight remaining moons of Jupiter are very small, and cannot be seen except with very large instruments. They remain unnamed, apart from the fifth, which seems to have become known as Amalthea – a name which is still 'unofficial', but as good as any other. In view of the desperate attempts to name every tiny asteroid, the failure to dignify Jupiter's satellites with proper titles seems rather remiss.

Amalthea is of definite interest. It was discovered by Professor Barnard in 1892, and is closer in than any of the Galileans;

it is about 112,000 miles from Jupiter's centre, and thus only about 70,000 miles above the outer cloud layers. It has a revolution period of only 12 hours, and is about 150 miles across, comparable to a fairly large asteroid such as Achilles.

Amalthea is so close to Jupiter that the gravitational strain upon it must be tremendous. Probably it is no longer strictly spherical; more probably it has been pulled into an egg-like shape, and as it has to complete one circuit of the Giant Planet every twelve hours its orbital speed is very high. In fact, there are indications that Amalthea is slowly spiralling down towards Jupiter. Its approach amounts to only an inch or two per year, and it has a reprieve of some seventy or eighty million years before disaster overtakes it; still, its expectation of life is short upon the cosmical time-scale.

From Amalthea, Jupiter would be a truly noble spectacle, covering a quarter of the sky – its belts, spots and turbulent clouds spread out in magnificent panorama against the starry background. Perhaps, in the distant future, men will go there and see these wonders for themselves. The sight of Jupiter in the Amalthean sky will be well worth the journey of four hundred million miles.

The remaining satellites fall into two groups, one (VI, VII and X) at about seven million miles from Jupiter, the other (VIII, IX, XI and XII) at about fourteen million. All are minute – VI about 100 miles across, the rest less than forty – and their only interest lies in their orbits, which are eccentric and inclined. Satellites VIII, IX, XI and XII have 'retrograde' motion – that is to say, they move round Jupiter in an east to west direction, instead of west to east. This leads automatically to the idea that all these tiny moonlets are nothing more than asteroids, perhaps Trojans, which came dangerously close to Jupiter and paid the penalty of forfeiting their independent status. There are certain mathematical objections to this theory, but at least it is a distinct possibility.

We know that landing on Jupiter is beyond our powers, but will it ever be possible to visit any of the satellites? There seems no reason why not, and in the far future there may well be a manned base on Io, Europa or even Amalthea; but we must remember that Jupiter is a long way away, so that unless we

can attain improbably high velocities a round trip will take six or seven years.

For ourselves, and for generations of men to come, there can be no hope of seeing the wonders of Jupiter from close range. We must be content to look at the king of planets from a respectful distance, and leave him alone in his cold, proud glory.

CHAPTER 12

Saturn

The outermost of the planets known to the ancients was named by them Saturn, after the God of Time. The name seemed appropriate, as the planet moved through the Zodiac at a very leisurely pace, and shone with a dull yellow light which made it look leaden and heavy. The old observers had no telescopes, and so they could not possibly tell that the dull, slow-moving planet that they dismissed in such a fashion is, in reality, the gem of the heavens.

Everyone knows that Saturn is the planet with the rings, and it is these rings which make it unique in the Solar System. Jupiter is larger and more important in the System as a whole; Venus and Mars are far more brilliant in terrestrial skies, but for sheer exquisite loveliness Saturn is unrivalled. The superb ring system which surrounds the yellow, flattened disk of the planet is alone in its glory, and its fascination never palls.

The splendour of the ring system tends to divert attention from the globe itself, and it is true that the surface details are none too easy to make out. Basically, Saturn is not unlike Jupiter, and it too has its cloud belts and its spots; but on the whole there seems to be much less violent activity. Saturn is a quieter world than its giant brother.

Saturn is appreciably smaller than Jupiter – the equatorial diameter is 75,000 miles, the polar diameter 67,000 – and twice as remote. The average distance from the Sun is 886 million miles, and travelling at its comparative crawl the planet takes 29 years to complete one revolution. As the axial rotation is rapid, about 10 hours, the Saturnian calendar must be highly complicated. In one year, there will be some 25,000 days. Nor could we divide the year into definite 'lunar months', as on Earth. We have only one moon, but Saturn has at least nine.

In size, Saturn is inferior only to Jupiter. Over 700 Earths could be packed inside its huge globe, but, strangely enough, it is curiously insubstantial; it weighs only 95 times as much as

our own world, and though its escape velocity is high (22 miles a second) the surface gravity is not. Surface gravity depends not only on the mass of a body, but also upon its diameter; for two globes of equal mass, the smaller (and therefore denser) will have the stronger surface pull. Because Saturn is so large, its surface gravity is much the same as the Earth's, and a man who weighed 14 stone here would weigh only just over 16 on Saturn. There is no planet in the Solar System, apart from Jupiter, upon which an Earthman would feel uncomfortably heavy.

Saturn's lack of mass is an indication of lack of density, and in fact the Ringed Planet turns out to be surprisingly light. Its average density is less than that of water. On Wildt's model, the rocky metallic core will be only 28,000 miles in diameter, with the ice layer 8,000 miles deep; the overlying gas-layer will be 16,000 miles thick, far more extensive, both relatively and actually, than that of Jupiter. Ramsey considers that Saturn is made up of about 60 per cent. by mass of hydrogen, and built in the same fashion as Jupiter.

One thing is certain: most of Saturn's mass is concentrated near the centre of the globe – the very marked polar flattening and the rapid axial spin prove this – and therefore the outer gas-clouds must be very rarefied. In 1920, two observers confirmed this by watching Saturn pass in front of a star, when for an appreciable time the star could actually be seen through the outermost layers of the planet. This is proof positive that the highest cloud-layers are semi-transparent.

As Saturn is almost twice as far from the Sun as Jupiter, we would expect it to be colder; and the measured temperature is indeed very low, about $-240°$ F. Consequently, more of the ammonia has frozen out of the atmosphere, and spectroscopes record much more methane than on Jupiter. The difference is probably due to nothing more fundamental than Saturn's lower temperature, and the gaseous mantle seems to be no whit less unpleasant so far as human beings are concerned.

Telescopes of fair size are needed to show much on Saturn's disk, but in general there seems to be a marked resemblance to Jupiter in one of its more quiescent moods. The Saturnian belts appear curved; the equatorial zone is generally brightish cream

in colour, and once again we have the phenomenon of different parts of the planet rotating at different speeds. The equatorial 'day' is about 10 hours 14 minutes, but in higher latitudes this may be increased by twenty minutes or more. Exact information is rather difficult to obtain.

Periodical outbursts of activity take place, particularly near the equator, comparable to a very mild Jovian outbreak; and there are times when a modest instrument is capable of showing considerable detail. For instance, numerous small spots, notches and 'festoons' appeared in 1951 and early 1952. However, there are no semi-permanent features comparable with the Great Red Spot or even the South Tropical Disturbance of Jupiter.

Major spots are very rare indeed, and the only really violent outburst of recent years took place in 1933. In August of that year a prominent white spot near the equator was discovered by W. T. Hay, an eminent British amateur astronomer – better known to the public, perhaps, as Will Hay, the stage and screen comedian. It rapidly became extremely conspicuous, partly because of its whiteness, and as a boy of nine I was easily able to see it with a 3-inch refractor. It gradually lengthened, and the portion of the disk following it darkened; subsequently the forward end of the spot became diffuse in outline, the following end remaining sharp and clear-cut. In the words of the Astronomer Royal, the appearance suggested "a mass of matter thrown up from an eruption below the visible surface, encountering a current travelling with greater speed than the erupted matter, which was carried forward by the current while still being fed from the following end". However, the spot did not last. It faded quickly, and in a few months was no more. Twenty years later, in 1953, another white spot was seen, but this was much inferior to Hay's in size and brilliance.

We cannot definitely account for these outbreaks, any more than we can for the Jovian ones, but the basic cause is almost certainly the same for the two planets. Saturn's comparative quiescence is due only to its lower temperature and lesser density.

However, it is the ring system which makes Saturn unique in its loveliness, and even though the rings are not of fundamental importance they have many features of absorbing interest. A

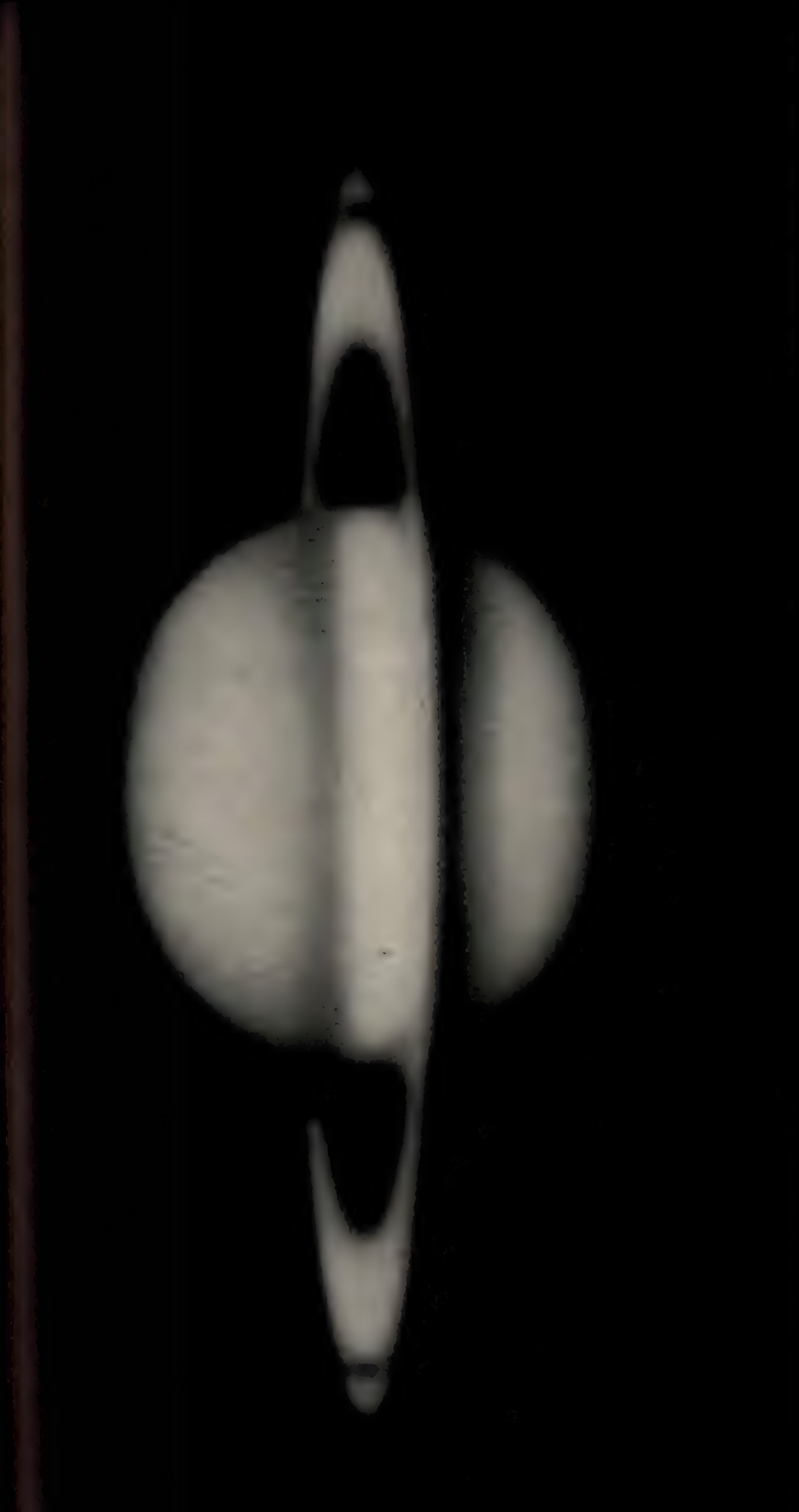


PLATE XXII. Saturn in blue light (photograph, Mount Wilson and Palomar Observatories). Taken with the 200-inch Hale Reflector

Plate XXIII. Two drawings of Saturn
(*Above:* 1951, June 10, 22h., $8\frac{1}{2}$-inch refl. × 300, Patrick Moore. *Below:* 1953, Apr. 20, 23h., 33-inch O.G. (Meudon Observatory) × 420, Patrick Moore)

small telescope will show them, though the more delicate features require a large aperture; and they have been known ever since 1610, when Galileo observed them (though not clearly enough to make out just what they were).

In 1659, Christian Huygens, a Dutch astronomer, issued a famous anagram[1] in which he announced that Saturn was surrounded by "a flat ring, which nowhere touches the body of the planet, and is inclined to the ecliptic". He was correct as far as he went, but it is now known that there are at least three principal rings, possibly four. A schematic drawing of the ring system is shown in Fig. 26.

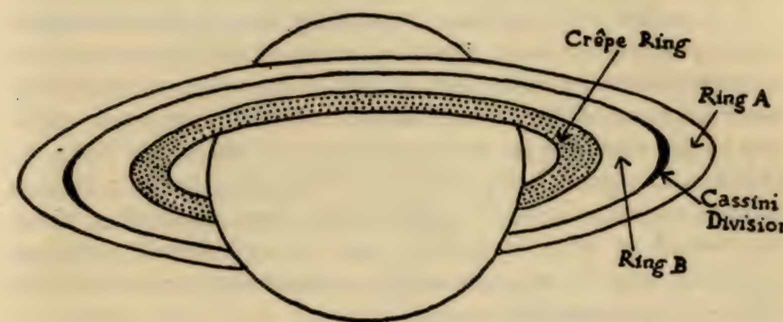


Fig. 26. Diagram of Saturn's ring system

The ring system is of vast extent. From tip to tip it measures almost 170,000 miles. The outermost ring, known as Ring A, is 10,000 miles wide; then comes a well-marked gap, known as Cassini's Division, with a width of 1,700 miles, and then Ring B, 16,000 miles wide. The 'ring' described by Huygens was a combination of A and B. His telescopes were not powerful enough to reveal the gap between them, and this feature was first described in 1675 by Jean Dominique Cassini, an Italian astronomer who had been called to Paris to direct the new observatory there.

[1] The anagram consisted of a number of letters arranged in alphabetical order, which, when rearranged, formed the Latin sentence: *Annulo cingitur, tenui, plano, nusquam cohærente, ad eclipticam inclinato*. In those days, before the laws of copyright came into existence, it was the custom to announce discoveries in anagram form. Galileo never succeeded in finding out the true nature of the rings, and was under the impression that Saturn was a triple planet.

Rings A and B are not alike. B is much the brighter of the two, and is less transparent; even a small telescope of good performance will show the difference, and the Cassini Division itself is not a difficult object with a 3-inch refractor when the rings are suitably placed.

Inside Ring B, between it and the planet, is a third ring, named Ring C but more generally known as the Crêpe or Dusky Ring. It was first recognized in 1850 by two independent observers, Bond in America and Dawes in England, and is comparatively inconspicuous; it is much less luminous than A or B, and is so transparent that the globe of Saturn can be seen through it.

It is rather odd that the Crêpe Ring should have remained undetected for so long. Herschel, the greatest observer of the eighteenth century, paid a great deal of attention to Saturn and observed most of the features known today; but although one or two of his drawings do show indications of the Crêpe Ring, he failed to recognize it for what it is. Nowadays it is far from a delicate object, and the suggestion has been made that it has brightened up since Herschel's time, though definite evidence is lacking and in any case such a brightening would be very difficult to account for.

The Crêpe Ring is 10,000 miles wide, and between it and the planet is a 'clear' area 9,000 miles in width, into which the Earth would fit quite comfortably.

The Cassini Division, separating Rings A and B, is not the only gap of its kind, though it is the only one within the range of ordinary telescopes. There is a narrower division in Ring A itself, discovered by the German astronomer Encke over a century ago and named after him; and gaps have been recorded both in Ring B and in the Crêpe Ring. In the *Strolling Astronomer* for November 1952, T. L. Cragg gave the following list of divisions recorded by members of the Association of Lunar and Planetary Observers:

(1) Cassini's Division, the prominent gap between Rings A and B.

(2) Encke's Division, between 6/10 and 7/10 of the way from Cassini's Division to the outer edge of Ring A.

(3) A division about 1/3 of the distance from the inner edge of Ring B to its outer edge, and on the outer border of the darker inner part of Ring B.

(4) A division about 2/3 of the distance from the inner edge of Ring B to its outer edge.

(5) A division separating Ring B from the Crêpe Ring.

(6) A division approximately in the middle of the Crêpe Ring.

All these divisions, apart from the first two, are very narrow and difficult to observe (I have yet to see them), and observers equipped with telescopes of moderate aperture can do valuable work in checking and confirming them.

A further point of interest in Cragg's report was that both he and T. R. Cave suspected a distinct 'dusky' ring outside Ring A. These were not the first observations of such a kind. An outer ring had been suspected as long ago as 1907, and in 1952 it was recorded again by R. M. Baum, in England. At present it must be regarded as 'non proven', but there is no theoretical bar to its existence.[1]

The shadows cast by the ring-system upon the disk of Saturn are easily seen, and unwary observers have often mistaken the main shadow for a surface belt. The disk, too, can cast shadow on the rings, as is well shown in the drawings in Plate XVII.

Despite their tremendous width, the rings are remarkably thin, and have been described as "the flattest things in the Solar System", which may well be true. Their thickness is probably not more than 10 miles, certainly not more than 40. If we reduce Saturn in scale to a globe with an equatorial diameter of five inches, the ring-span will be one foot; but the ring thickness will be only $\frac{1}{1500}$ of an inch – one-third the thickness of an ordinary sheet of writing paper.

This thinness has important consequences so far as we are concerned. When the rings are turned edge-on to us, they almost disappear. Every fourteen years or so, the Earth passes through the plane of the ring-system, and in a small telescope the planet

[1] I made a special search for it with the 33-inch refractor at Meudon, in 1953, without success. Seeing conditions, however, were not first class.

appears as a mere ball, crossed by belts and shadows. A larger instrument will show the ring-system as a hair-line of light, as was the case in 1951. The rings will be fully opened for our inspection in 1958, after which they will gradually close again, returning to the edge-on position in 1966.

The reason for this behaviour is that Saturn's rings are exactly in the plane of the planet's equator, which is tilted to the Earth's orbit at an angle of 27°. Sometimes we look 'down' at the rings, sometimes 'up'. This can be made clear by a simple experiment. Prop up a saucer at eye-level in the manner shown in Plate XXIV, and walk round it. Twice in each revolution the saucer will appear edge-on; twice you will see the full surface – once the front, once the back. The analogy is not entirely correct, and in any case the saucer's thickness is much greater relatively than that of the ring-system, but the principle is clear enough.

The two brightest rings, A and B, look so solid telescopically that it was natural for the early observers to regard them as either solid or liquid. Unfortunately for this theory, Clerk Maxwell showed in 1859 that no ring of this sort could manage to survive. The entire system lies within the gravitational 'danger-zone' of Saturn, known technically as the Roche limit. Any solid or liquid ring would be literally torn to pieces by the tremendous pull of the planet, and we must look for another explanation.

J. J. Cassini, son of the discoverer of the principal Division, made the shrewd suggestion that the rings might not be continuous at all, but composed of thousands upon thousands of small solid particles – tiny 'moonlets', in fact – each turning round the planet in its own individual orbit. For many years this idea was put aside, but later investigations have shown that it is correct. It accounts for the transparency of the rings, and also for the fact that the inner parts rotate round Saturn more rapidly than the outer.

We can only guess at the sizes of the particles which make up the rings. As they are highly reflective, it seems probable that most of them are very small, ranging from lumps the size of table-tennis balls down to coarse dust; material in the pulverized state is very efficient at reflecting light. When the rings are fully

presented to us, they actually send us more light than the globe itself, so that Saturn will appear unusually brilliant in 1958.

Nor can we gain much information about the nature of the ring material. It may be rock of some kind; but Kuiper, who has examined the rings spectroscopically, believes that the particles are made up either of ice or of some frost-covered substance. We can at least be sure that they are very cold.

It is interesting to speculate as to how the rings were formed. They may be due to a 'celestial shipwreck', the destroyed vessel being a former satellite which was incautious enough to come within the Roche limit for Saturn, and paid the supreme penalty

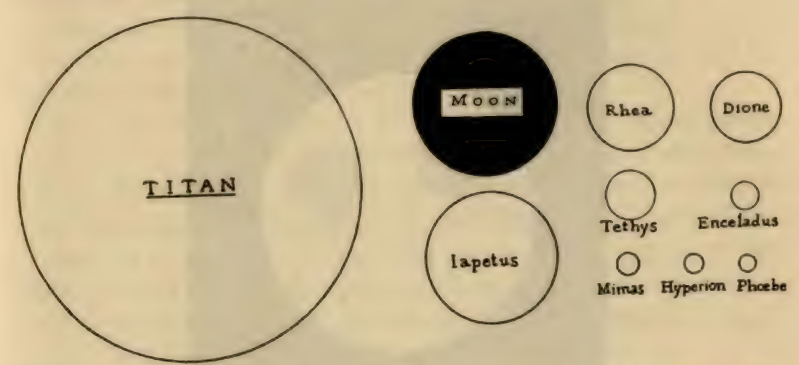


FIG. 27. Sizes of Saturn's satellites compared with the Moon. Diameters extremely uncertain

of being broken up and spread round the planet in a swarm of minute particles. An alternative idea is that the rings were never any more continuous than they are now, and that they, as well as Saturn's five inner satellites, condensed out of a former surround of widespread, tenuous matter. At present we cannot be certain; but however the ring system came into being, it is unique – unrivalled, so far as we know, not only in the Solar System but in the universe.

Saturn, like Jupiter, has a wealth of satellites. Nine are definitely known, and a tenth has been suspected. Only one – Titan – is of planetary dimensions, but this makes up for all the rest, as it is the largest satellite in the Solar System and is the only one definitely known to possess an atmosphere. Its diameter is

to some extent uncertain, but appears to be about 3,500 miles, intermediate in size between Mercury and Mars; and its comparatively high escape velocity – over 2 miles a second – makes it capable of holding down an appreciable gaseous mantle.

The atmosphere was discovered spectroscopically by Kuiper, in 1944. At first sight it seems rather unprepossessing, since it consists mainly of poisonous methane; yet it may well have its uses in the centuries to come. Methane is a rocket propellent, and we shall be able to set out for the Saturnian system with the certainty that we shall be able to refuel when we get there

FIG. 28. Titan (33-inch Meudon refractor, ×540; H. P. Wilkins)

– which is more than we can say about Jupiter, short of attempting the impossible and landing on the planet itself.

Even though Titan is large, it is so remote that its surface details are very hard to make out, and even with the Meudon telescope Dr. Wilkins, in 1953, was only able to detect two dusky patches (Fig. 28). In common with the other satellites of both Jupiter and Saturn, Titan seems to keep one face turned permanently towards its primary, so that it has a 'day' and a 'month' both equal to about 16 terrestrial days.

Titan can be seen with any small telescope, and was discovered (by Huygens) as long ago as 1655, so that it was the first satellite to be found apart from the four Galilean moons of Jupiter.

It is distinctly yellowish, and appears to be fairly dense, though its mass is not known with any accuracy. It is some 760,000 miles from Saturn, and is the sixth satellite in order of distance from the planet.

The five inner satellites, Mimas, Enceladus, Tethys, Dione and Rhea, are much smaller, and appear to be very light, so that they are probably composed of packed ice and rock of the pumice type. In Kuiper's view, Mimas and Enceladus at least, and probably Tethys also, are principally 'atmospheric condensations', mainly water ice and ammonia ice. Together with Titan, the five inner moons are responsible for the Divisions in the ring-system. Mimas must have a particularly powerful pull upon the ring particles; although only some 350 miles across, it is a mere thirty thousand miles from the edge of Ring A, not far outside the Roche limit for Saturn.

Dione, the fourth satellite, is of some interest. Its diameter is perhaps 1,000 miles, and it is considerably larger and more massive than Tethys, but it is no brighter – indeed, Tethys is often the more conspicuous of the two. Evidently Dione is less efficient as a reflector. It is about as far from Saturn as the Moon is from the Earth; yet the Moon takes over 27 days to circle once, while Dione whirls round Saturn in a period of only 2 days 17½ hours.

Rhea, fifth in order of distance, is over 1,000 miles across, and is quite easy to pick up in a modest instrument; but Hyperion the seventh moon, is very minute, probably only about 200 miles across. The best time to find it is when it lies close to Titan in the sky. I have picked it upon favourable occasions with my 12½-inch reflector, and most text-books state that it is fainter than is actually the case.

Iapetus, the eighth satellite, is perhaps the most interesting of all. Here again, the diameter is uncertain; older values of about 1,000 miles have been found to be much too small, and 2,000 is probably nearer the mark, so that Iapetus is not much smaller than the Moon. It is a long way from Saturn – over two million miles – and has a 'month' of 79 days; its mass and escape velocity are most uncertain, and it is just possible (though unlikely) that it may be able to hold on to a very tenuous mantle of atmosphere.

The main peculiarity of Iapetus is that it varies in brilliance. When at its greatest distance west of Saturn in the sky, it is not much fainter than Titan, and can be seen easily with a 3-inch refractor. About five weeks later, when it is east of the planet, the brightness has fallen away so greatly that Iapetus is much inferior to either Tethys or Dione. These variations are quite regular, and have been known for many years.

Obviously, some surface peculiarity is at the root of this queer behaviour; and as Iapetus is too small and remote for any physical details to be made out, we are reduced to guesswork. Whipple has suggested that one side reflects better than the other, and that in the remote past Iapetus was either disfigured by collision with a wandering body, or discoloured by gaseous outbursts from Saturn. Since it is highly probable that Iapetus obeys the general rule of having an equal day and month, this suggestion has something to recommend it, though on the gaseous outburst theory it is not easy to see why Iapetus, and Iapetus only, should have been affected.

An alternative suggestion is that some sort of surface deposit is responsible. If Iapetus retains any atmosphere, the gaseous mantle may freeze during the bitter 40-days night, when the temperature must drop to a value not very far above absolute zero; and it is within the bounds of possibility that the brightness at western elongation is due to the solar rays striking this frozen deposit. Unfortunately we have still to explain why Iapetus is alone in its oddness, and in any case it seems unlikely that the escape velocity is high enough for it to retain any atmosphere at all.

The outermost of Saturn's moons, discovered by Barnard in 1898, is named Phœbe. Although very small, probably smaller than Hyperion, it has an interesting orbit, fairly circular but highly inclined; and it is so far from Saturn – over eight million miles – that it takes a year and a half to complete one revolution. Moreover, it, like some of the minor members of the Jovian family, moves the wrong way, and travels from east to west instead of from west to east.

Satellite No. 10, announced by Pickering in 1904, must be regarded as a 'ghost'. Its movements, its distance from Saturn, and its periodic time were worked out, and it was even given a name, Themis; but it has never been seen again, and in all probability it does not exist. Pickering was a fine observer, but even the best of observers makes a mistake occasionally, and Themis is now looked on as the 'Vulcan' of the Saturnian system.

It would take a long time to reach Saturn. At speeds which we consider may be possible within the next few centuries, the round trip would take seven years, and needless to say it will not be accomplished for many generations yet – though, as A. C. Clarke pointed out in a famous story,[1] Saturn's system may be reached before Jupiter's, owing to the convenient methane supplies waiting for us on Titan. But suppose we could really make the journey – what would we see? We cannot go there in fact, so let us amuse ourselves by doing so in imagination.

We land first on Phœbe, the tiny outermost moon, where the gravitational pull is so feeble that ordinary walking is out of the question, and we have to rely upon the rocket-powered space-suits which we found so useful on Deimos. The sky is black; the little moon has no vestige of air, and the Sun, a pitifully shrunken globe covering only 1/90 of the area it does from Earth, seems to have little power of warmth, so that the temperature is terribly low – about –240° F., colder than any place we have yet encountered apart from the night side of Mercury.

High in the sky, eight million miles away, we can see Saturn, looking about as large as the Moon from the Earth. Its rings are glorious, even at this distance; the Cassini Division can be clearly seen, even the Crêpe Ring and the surface belts. Strung out in a line, like so many diamonds against the blackness, are the other satellites; two of them seem to have minute disks, Titan (because it is so big) and Iapetus (because it is fairly big, and also much closer to us than the rest). The strong yellow light of Saturn floods down upon the barren surface of Phœbe, bathing the little world in a glow which seems almost warm and friendly.

Let us move in to Iapetus, two million miles or so from Saturn's surface. Here the surface gravity, though weak, is enough for us to walk more or less normally; the sky is black, of course, but the Ringed Planet is noble indeed, dominating the entire heavens and casting a strong radiance across the Iapetan

[1] *The Sands of Mars*, 1951.

rocks. We note that Saturn shows a phase; it is a crescent, yet the 'dark' side is faintly illuminated by the glare from the encircling rings. The ring-system, however, is less open than we had hoped, and even from here it still looks solid, as if made up of a sheet of matter instead of swarms of particles.

What of the other planets? We look in vain for Earth and Mars; both are too faint, and too close to the Sun, to be made out. Jupiter shines from the blackness, not far above the sharply-curving horizon, and our binoculars reveal that it, too, shows a phase; but it appears little larger than from the Earth, and we realize that Saturn is not a good place from which to view other members of the planet family. Only the three outermost members, Uranus, Neptune and Pluto, can be seen even reasonably well.

If we move in to Titan, only a little over 700,000 miles from the outer clouds, we notice great changes. For one thing, the sky is blue, not black. Titan's methane atmosphere is quite efficient at scattering light, and the hue of the heavens reminds us rather of the Martian sky. The landscape is broken and rugged, with peaks here and there, and in the distance we can see a glittering area which looks almost like a pool – perhaps a pool of liquid ammonia.

Saturn is a grand sight, but if we move still farther in, to Rhea, it will be even more imposing. Now we can see detail upon the huge globe; there are spots, hollows, notches and festoons in the belt areas, and there is colour too, ranging from the bright creaminess of the equator to the dusky greenish shades of the polar regions. But we are disappointed to see that the rings are almost edge-on to us, so that their full splendour is lost. How long must we wait for them to open out?

It comes as a surprise to learn that they will never open out. All the satellites of Saturn, apart from Iapetus and Phœbe, move almost exactly in the plane of the equator, which is also the plane of the rings; and so the inhabitants of Rhea, if they existed, would never have the joy of seeing the ring-system fully presented. Oddly enough, the best view of the rings would be had from distant Iapetus.

Lastly, let us visit Mimas, nearest of all the moons. Here again the rings will be edge-on to us; but they will stretch almost across the sky, and the vast yellow globe of Saturn itself will seem to cover an area 5,000 times as great as the Moon does as seen from the Earth. We weigh almost nothing on Mimas; once again we have recourse to rocket suits, but the magnificence of the spectacle is enough to compensate for any discomfort.

Saturn is partly above and partly below the horizon, dazzlingly brilliant, and far more imposing than the shrunken Sun. The cloudy, turbulent belts can be seen in all their complexity; across the disk runs a broad, dark band, which we realize must be the shadow of the ring-system. In the sky shine several moons. We can make out the crescents of Tethys and Dione in the west, Rhea and Enceladus in the east, while the yellow disk of Titan almost touches the edge of Saturn's globe. The light is strong across the icy surface of Mimas, and the spots and belts drift slowly but surely as Saturn spins on its axis.

Such would be Saturn, seen from close quarters. Our eyes will never feast upon such a spectacle; but let us be grateful that, at least, we have telescopes powerful enough to show the Ringed Planet in some part of its glory. As Saturn swims into view, cold, remote, lonely and unutterably magnificent, it makes a picture which no-one who has seen it will ever be likely to forget.

CHAPTER 13

Uranus

We do not know who first discovered Mars, Jupiter and the other brilliant planets. They are so conspicuous in the night-sky, and their movements are so pronounced across the starry background, that they must have been recognized at the dawn of history. The mandarins of ancient China, the builders of the Pyramids, the architects of Cnossos knew them well, and even the men of the Stone Age must have realized that they were not ordinary stars.

Even when it was still thought that the Earth was the centre of the universe, Mercury, Venus, Mars, Jupiter and Saturn were regarded as very near neighbours. These five, together with the Sun and Moon, made up seven 'planetary' bodies. Seven was the magical number, therefore it seemed only proper to suppose that there were seven planets; what could be more reasonable?

Kepler had his doubts, and thought that there might be a small planet between Mars and Jupiter. Bode and Titius came to the same conclusion. However, it does not seem to have occurred to anyone that there might be a planet far out in the twilight regions beyond Saturn; and the amazing discovery made by a young musician-astronomer in the year 1781 came as a staggering surprise to the scientific world.

William Herschel, the man responsible, was a Hanoverian who had settled in England and had become an organist. About 1772 he began to develop an interest in astronomy, and between that date and the end of his long life, in 1822, he accomplished a remarkable amount of work. He became by far the most skilful instrument-maker of his time; he was the founder of true 'stellar astronomy', the study of the stars; he made many important observations of the planets, and discovered a number of satellites. Every possible honour came his way. He received a knighthood, became the King's Astronomer, and at the very end of his life was the first president of the newly-founded Royal Astronomical Society. His main work was in connection with

the stars, and his planetary studies were more or less incidental; nevertheless, he is perhaps best remembered as the man who pushed the known frontiers of the Solar System far beyond their ancient limits.

On March 13, 1781, Herschel was busy examining some faint stars in the constellation Gemini, the star-group which contains the famous 'twins', Castor and Pollux. In his own words, he "perceived one star which appeared visibly larger than all the rest", and "suspected it to be a comet". Further observations showed that it was not a comet at all, but a new major planet.

It has often been said that the discovery was sheer chance, but this view is distinctly unfair to Herschel. He was engaged upon a systematic review of the entire sky, and as he himself pointed out in a letter written to a friend of his, Dr. Hutton: "Had business prevented me that evening, I must have found it the next, and the goodness of my telescope was such that I must have perceived its visible planetary disk as soon as I looked at it." As a matter of fact, his telescope was only a modest 6¼-inch reflector of his own manufacture, and his confidence in his ability to detect anything unusual is fitting testimony not only to his patience but also to his eyesight.

Herschel was not the first to record the new planet. It had been seen on several previous occasions, and the first Astronomer Royal, John Flamsteed, recorded it six times between 1690 and 1715 without realizing that it was anything but an ordinary star. Keen-sighted persons can just see it without a telescope at all, provided that they know exactly where to look.

It is interesting to note that the discovery could hardly have been delayed for more than twenty extra years. Had Herschel failed to recognize the planet for what it was, it could not have escaped the search organized by Schröter and von Zach in the first years of the nineteenth century. It would indeed have been remarkable if the 'asteroid hunters' had been rewarded by the detection of a new major planet far beyond the known limits of the Solar System.

Several rather unsuitable names were suggested for this new body, but before long Bode's suggestion of 'Uranus' came into general use. For Herschel, the discovery was the turning-point of his career. He received a royal grant which enabled him to

give up music as a profession, and henceforward he devoted all his time to science – to the great benefit of astronomy in general, stellar astronomy in particular.

Uranus is very remote. Its mean distance from the Sun is 1,782 million miles, and since the orbit is almost circular this does not vary much either way. Naturally, it is slow-moving, and plods along at a mere 4 miles a second, so that it takes a long time to complete one circuit. A full revolution takes 84 years, so that its discovery by Herschel occurred only just over two Uranian 'years' ago.

In size, it is intermediate between Saturn and the Earth, but it certainly ranks as a giant rather than as a terrestrial planet. The diameter is about 32,000 miles, and it is perceptibly flattened at the poles. It is denser than water, and much denser than

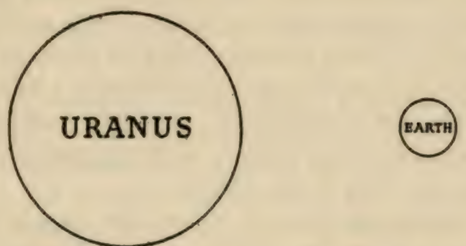


FIG. 29. Comparative sizes of Uranus and the Earth

Saturn; but volume for volume it weighs rather less than Jupiter. Though it could contain 64 Earths, it only weighs as much as 15.

Wildt has worked out a model for Uranus much as he has done for Jupiter and Saturn, and has found that the rock core has a diameter of 14,000 miles, with a 6,000-mile ice-layer and a gaseous mantle 3,000 miles deep. Ramsey considers that Uranus is "presumably composed of water, methane and ammonia, together with terrestrial materials".

Analysis of the outer cloud-layer is much more difficult than in the case of Saturn, as Uranus is not only much smaller but also twice as far off. However, it seems definite that there is a great deal of methane, and only a trace of ammonia vapour. This is to be expected, since the temperature is very low indeed (in the region of −310° F.), and nearly all the ammonia must be in a

frozen state. Recently, G. Herzberg, at Ottawa, has detected free hydrogen, and concludes that helium gas is also present.

Despite Uranus' great size and mass, and its high escape velocity – 13 miles a second – surface gravity there is actually slightly less than on the Earth. This is because of the fact noted earlier, that surface gravity depends not only upon mass but also upon size; hence, indirectly, upon density. A man transported to the surface of Uranus would feel slightly lighter than at home, though the difference would be very small.

The axial rotation of Uranus, like that of Jupiter, is very rapid. The best value so far obtained is 10¾ hours, so that there are about 65,000 'days' in each Uranian year. However, it is not the rate of spin which is so peculiar, but the angle. As we have

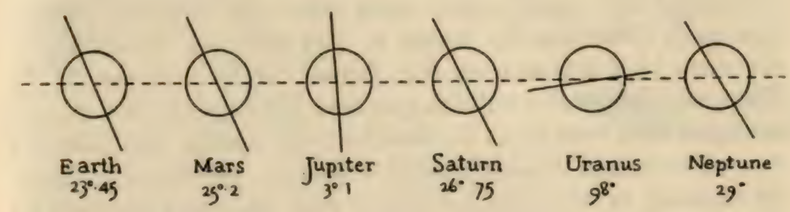


FIG. 30. Inclinations of the axes of rotation of the planets, with reference to their orbits (inclinations of Mercury, Venus and Pluto unknown)

seen, all the major planets we have so far examined rotate with their axes not greatly inclined to their orbits (apart possibly from Venus, about which we know practically nothing). Uranus has its own way of behaving. The axial tilt is actually more than a right angle, and Uranus rolls along its orbit almost pole-first, as is shown in Fig. 30.

As a result of this, the 'seasons' on Uranus are peculiar, to put it mildly. First much of the northern hemisphere, then much of the southern will be plunged into Stygian blackness for 21 years at a time, with a corresponding 'midnight sun' in the opposite hemisphere. For the rest of the Uranian year, 48 terrestrial years, day and night conditions will be more normal.

The unusual tilt of Uranus' axis also means that we shall sometimes look straight at a pole, sometimes at the equator. In

1945, for instance, the pole was presented, and appeared near the centre of the apparent disk. By 1966, the equator will be running across the disk-centre, with the poles at the limbs to either side (Fig. 31). The surface appearance must consequently be most odd, but unfortunately the planet is so remote that not even large telescopes will show much.

In powerful instruments, Uranus appears as a pale greenish globe with a whiter equatorial zone (perhaps similar to Saturn's), and faint belts. These features are well shown in the drawings given here. With a small telescope, nothing can be seen of Uranus apart from its minute, greenish disk.

Despite the difficulty of making physical observations, interesting things are seen now and then. On 1949 February 23, for example, Dr. Armellini at Rome, using a 16-inch refractor, discovered two small white spots near the equator, perhaps similar to those seen on Saturn in 1933 and 1953. Something of the same kind was seen on 1952 January 16 by Professor W. H. Haas, who recorded a whitish spot near the edge of the disk; this had also been seen by O. C. Ranck a week earlier, and from the two observations Haas deduced a rotation period of 10 hours 46 minutes, in excellent agreement with the value obtained by less direct methods. Haas re-observed the spot on January 24 and February 2, though less prominently. On February 11 of the same year, Ranck drew a bright circular spot near the centre of the disk, which – as polar presentation had occurred only seven years before, not long on the Uranian time-scale – may have been a brightening in the polar region. Other whitish areas were seen later in 1952 by Dr. A. G. Smith, at the University of Florida, and altogether the planet seems to have been unusually active during this period.

Up to very recently, it was believed that Uranus was even more quiescent than Saturn, and that surface disturbances were mild and infrequent. The 1952 observations seem to indicate that we may have to revise our ideas, and equally important work done by German observers leads us to a similar conclusion. The Germans have found that Uranus shows strange fluctuations in brilliancy, and their work has been summarized by Günter D. Roth, one of the leading European planetary observers of today.

Some variations in brightness are to be expected; there are

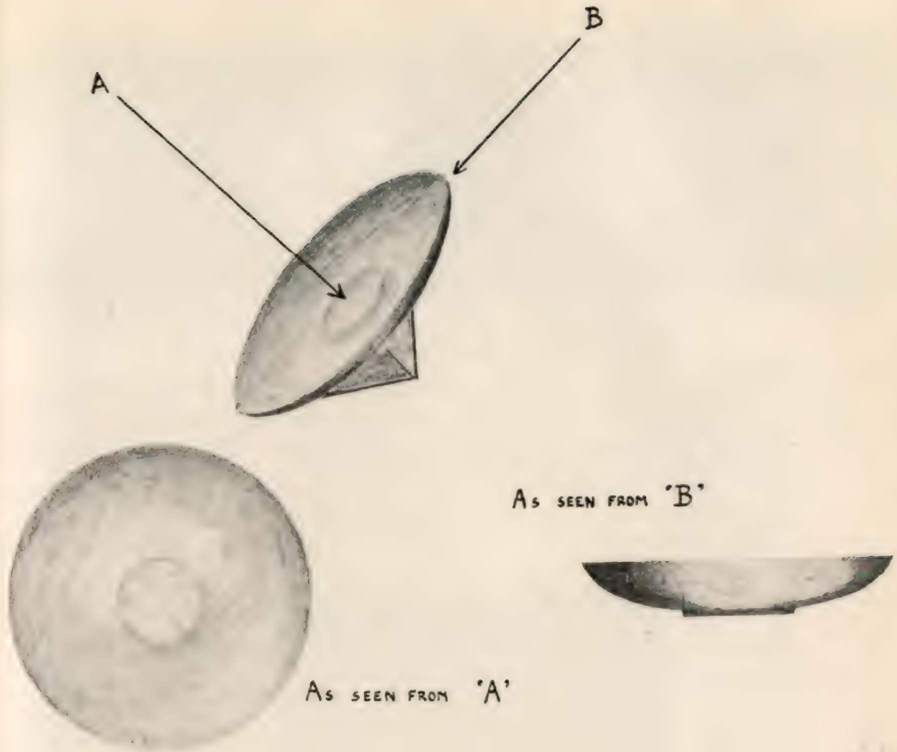


Plate XXIV. Three views of a saucer (A. L. Helm)

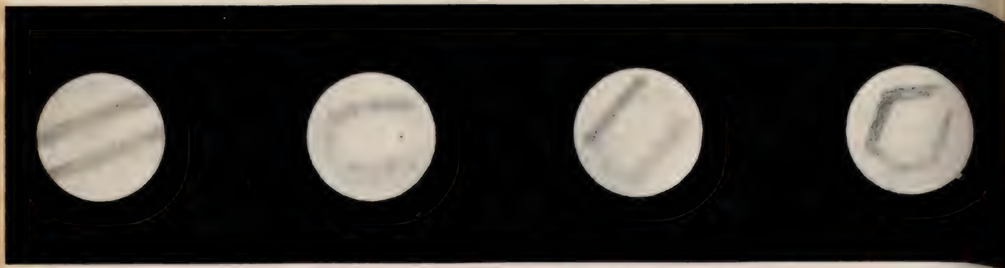


PLATE XXV. Four drawings of Uranus

(*Left:* 1941, Mar. 16, 8h., 18-inch O.G. ×300, F. Vaughn. *Left centre:* 1952, Jan. 20, 11h., 18-inch O.G. ×400, W. H. Haas. *Right centre:* 1952, Feb. 25, 10h., 18-inch O.G. ×400, W. H. Haas. *Right:* 1952, Mar. 11, 8h., 18-inch O.G. ×400, W. H. Haas)

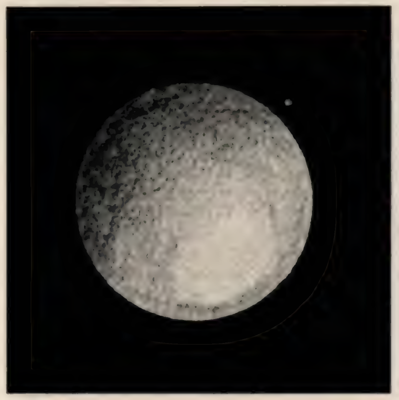


PLATE XXVI. Uranus (1954, Jan. 13, 23h. 50m., 12½-inch refl. ×500. Patrick Moore)

many factors to be taken into account. When Uranus is near perihelion, it will be more brightly lit than when more remote from the Sun, and so will increase in apparent brilliancy; closeness to the Earth near the time of perihelion will result in an extra increase, and we must remember the strange axial tilt, which also plays a part. When the pole is presented to us, as in 1945, Uranus will show a larger surface area than at other times. (This can be made clear by holding up an egg first with the thin end presented and then broadside-on, though naturally the flattening of Uranus is much less than in the case of the egg.)

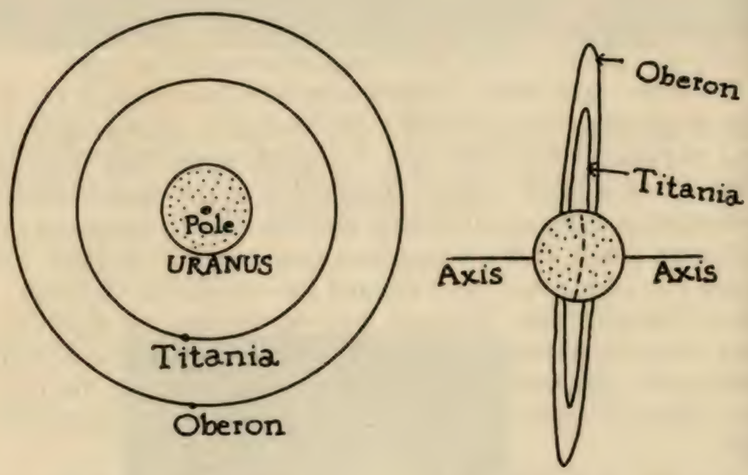
However, these fairly obvious factors do not account for all the brightness changes actually observed, and the rest must be due to physical causes. In 1917, Campbell, at the Lick Observatory, found a small regular change due to the axial rotation; astronomers at Potsdam detected another, due to changes in the reflecting power of the atmosphere over a period of years. Yet when everything had been allowed for, six skilful observers – Roth, Malsch, Neis, Rügemer and van Schewik in Germany, and Haupt in Austria – discovered that there was still a marked discrepancy between predicted and actual brilliancy. In 1949, for instance, Uranus was appreciably fainter than it should have been.

It seems probable, therefore, that considerable disturbances are taking place on the surface; Uranus may indeed be more active than Saturn, though it is much too early to form any definite conclusions. More detailed information would be of great interest, and it is unfortunate that Uranus is so far away that very large apertures are needed to see it even moderately well.

As befits its status as a giant planet, Uranus is surrounded by a retinue of attendants. Herschel believed that he had discovered six, but for once he was mistaken; four of his 'satellites' were in reality small stars, and only two, those now known as Titania and Oberon, were genuine articles. Two more, Ariel and Umbriel, were found in 1851 by an English astronomer, Lassell; while the fifth and faintest of the family, Miranda, was detected by Kuiper, at the McDonald Observatory in Texas, as recently as 1948.

All five satellites revolve almost in the plane of Uranus' equator, and consequently their paths appear circular when the

pole is presented to us, almost straight up-and-down lines when the equator is central on the disk (Fig. 31). Their distance range from 76,000 miles from the planet (Miranda) to 364,000 miles (Oberon), and it is possible that they, like Uranus, roll along almost pole-first in their orbits, though there is no real reason to suppose that they form exceptions to the general rule that



(A) 1945. The pole of Uranus is presented, and the orbits of the satellites appear circular

(B) 1966. The equator of Uranus is presented, and the orbits of the satellites appear highly elliptical

FIG. 31. Apparent orbits of the satellites of Uranus. Only the two outer satellites (Titania and Oberon) are shown, and the drawing is not to scale

satellites revolve with the same hemisphere permanently facing their primaries.

The brilliancies of the four main satellites have often been underestimated. It is true that they are not easy objects, but in 1947 Dr. W. H. Steavenson examined them with his great 30-inch reflector at Cambridge University, and found that they are much brighter than had generally been supposed. He also found that both Titania and Oberon vary considerably, and there may be some similarity between their behaviour and that of Iapetus,

though it is still uncertain whether the variations are regular or not.

Adopting Dr. Steavenson's revised estimates of brilliancy, and assuming that the satellites have normal reflecting powers, it seems that Ariel, Titania and Oberon may be between 1,300 and 1,800 miles in diameter, Umbriel between 700 and 900, and Miranda 200; but these values are still most uncertain. At any rate, the escape velocities must be low, so that none of the five can have managed to retain any appreciable mantle of atmosphere.

It need hardly be said that we need not waste time working out the possibility of a journey to Uranus. The planet is so distant that even light, racing through space at 186,000 miles a second, takes almost three hours to get there; and a voyage at anything like the probable speed of a space-craft would take over twenty years for the round trip. Moreover, there is no convenient methane-mantled satellite waiting for us. Uranus must be left to roll along in its icy solitude, remote, unwelcoming, and lonely beyond our understanding.

CHAPTER 14

Neptune

Far away in the depths of space, a thousand million miles beyond Uranus, lies the last of the giant planets – Neptune, a lonely, frozen giant bathed in perpetual half-light, and so remote that we cannot see it at all without a telescope. Neptunian astronomers, if they existed, could know nothing about the Earth; but, strangely enough, terrestrial astronomers knew that Neptune existed before they actually observed it at all. The story of its discovery is certainly worth re-telling.

The key to the problem was provided by Uranus. As we have seen, Uranus had been recorded several times before Herschel recognized it as a planet; Flamsteed noted it half a dozen times, and so did a French astronomer named Le Monnier. Flamsteed never checked the observations, and Le Monnier was certainly not blessed with an orderly and methodical mind. However, when mathematicians came to compute the orbit of the newly-found Uranus, they found the old observations most useful – even one of Le Monnier's which was recorded in pencil on the back of a bag which had once contained hair perfume![1]

Altogether, recordings of Uranus extended back over a hundred years before 1781, more than one complete revolution of the planet, and it should have been possible to work out a reliable orbit. Unfortunately, the old observations did not seem to fit properly with those made after 1781. Something was wrong somewhere, and eventually a French mathematician, Alexis Bouvard, rejected the old observations altogether and worked out a new orbit based only upon positions measured after Uranus' recognition as a planet.

Even this would not do. Uranus refused to behave; it persistently strayed from its predicted path. Up to 1822 it seemed to move too rapidly; after 1822, it lagged, and it became painfully clear that there was some unknown factor to be taken into account.

[1] Le Monnier seemed fated to miss perpetuating his name. While engaged upon cataloguing the stars near the north celestial pole, he introduced an entirely new constellation, Tarandus (the Reindeer) which was promptly forgotten. Le Monnier was undoubtedly a clever scientist, and did much valuable work, but it was said of him that he quarrelled with every person with whom he came in contact.

Although the planets move in fairly direct paths round the Sun, each pulls upon its fellows; thus the Earth is appreciably perturbed by Venus and Mars, and to a lesser extent by the more remote planets also. The most powerful known disturbing agents so far as Uranus was concerned were Saturn and Jupiter, but Bouvard had allowed for them both, and still Uranus wandered.

In 1834 the Rev. T. J. Hussey, Rector of Hayes in Kent, made a most interesting suggestion. Suppose that an unknown planet was pulling on Uranus? This might account for its refusal to follow the predicted path; and by working backwards from the disturbances observed, it might be possible to track down the planet responsible.

Hussey went so far as to write a letter to George (afterwards Sir George) Airy, the Astronomer Royal of the time, but Airy was not encouraging. However, in 1841 a young Cambridge student, John Couch Adams, made up his mind to attack the whole problem as soon as he had taken his mathematical degree. He passed the final examinations (brilliantly) in 1843, and then began to study the movements of Uranus in earnest. By the end of the year he had worked out just where the unknown planet ought to be, and, naturally enough, he sent his results to Airy.

Now began a series of misfortunes which led to a most undignified dispute in after years. Airy, partly through lack of confidence in Adams and partly through a misunderstanding, took no action. Delay followed delay, until in 1846 Urbain Le Verrier, a French mathematician, published a memoir which showed that he had approached the problem much as Adams had done, with similar results.

As soon as Airy received Le Verrier's memoir, he asked two observers – Professor Challis, at Cambridge, and an amateur, William Lassell – to begin searching in the place indicated by Adams. Still there were delays. Challis had no suitable star-maps of the area, while Lassell was rendered *hors de combat* by a sprained ankle. Challis actually recorded the object he was seeking on August 4 and again on August 12; but he failed to com-

pare the observations, and before he had done so Johann Galle and Heinrich d'Arrest, working at Berlin Observatory upon Le Verrier's calculations, had found and identified the new planet.

Adams had been the first to forecast the planet's position; Le Verrier's work had led to the first actual identification, and both mathematicians were deserving of the highest praise. Unhappily, they were made the centre of a childish squabble about priority, which is best forgotten – and in which neither of the principals took part. Even the scientific world is not entirely free from jealousy, but wrangles of this nature cannot be defended. It is the discovery which matters, not the man who makes it.

Neptune, as the new planet was named, proved to be a giant, very similar to Uranus but much more remote. On the average, it is 2,793 million miles from the Sun, and has a periodic time of 164¾ years, so that not until 2011 will it return to the part of its orbit at which it was first recognized by Galle and Challis. The tilt of its axis is normal (about 35°), so that the peculiar seasonal effects of Uranus do not occur; and the rotation period is fairly short, in the region of 15¾ hours. There are thus over 90,000 'days' in the Neptunian year.

As soon as Neptune was discovered, the orbit of Uranus was re-calculated, and this time the old observations of Flamsteed and Le Monnier fitted almost perfectly into place. It is interesting to note that Neptune was in 'opposition', so far as Uranus is concerned, in 1822; the Sun, Uranus and Neptune were then almost in line, with Uranus in the middle. Before 1822, Neptune was tending to pull Uranus along; after 1822, it tried to drag it back, which accounted excellently for the perturbations observed. Had Uranus and Neptune been on opposite sides of the Sun in the early nineteenth century, the disturbing effects upon Uranus would have been inappreciable, and Neptune's discovery might have been considerably delayed.

Until the last few years, Neptune was believed to be larger than Uranus, but recent measures by Kuiper at the McDonald Observatory in Texas show that it is smaller, with a diameter of about 27,600 miles. It is, however, the more massive of the two. It is as heavy as 17 Earths, and is the densest of the four giant planets, which accounts for the fact that it is only slightly flattened at the poles. The surface gravity is also higher than that of Uranus. A man who weighs 14 stone on Earth would weigh nearly 20 stone on Neptune.

According to Wildt, the rocky core is 12,000 miles in diameter, the ice layer 6,000 miles thick, and the outer gas 2,000 miles deep; Ramsey considers that Neptune's composition is almost exactly the same as that of Uranus. Certainly the outer clouds contain a good deal of methane. There is a certain amount of free hydrogen, and probably helium; but ammonia vapour is absent, as we might expect. The bitter cold, −360° F., is enough to freeze practically all the ammonia out of the atmosphere.

Surface details on Neptune are extremely hard to make out; only a very large telescope will show anything at all. The drawing in Plate XXIX, made by T. L. Cragg with a power of 1,000 on the 60-inch reflector of the Mount Wilson Observatory, shows a brightish equatorial zone with duskier poles, which is about as much as is ever seen. It has been suggested that Neptune is a comparatively quiet world, with little surface activity; and this seems very probable, bearing in mind the intense cold and the fact that almost all the ammonia has been frozen out of the atmosphere. However, we must be wary. We have had to revise our ideas about Uranus, and Uranus and Neptune may be regarded as twins.

Neptune has only two known satellites, but both are of unusual interest. The first, Triton, was discovered by Lassell only three weeks after Neptune itself had been found, and is the most massive satellite in the Solar System, if not the largest. The diameter is at least 3,000 miles, and it is possible that the mass is as great as that of Mercury, though no accurate estimates have been made as yet. The escape velocity must be fairly high, and an atmosphere is therefore to be expected. Traces of methane were suspected by Kuiper in 1944, and though they have not so far been confirmed there is little doubt that Triton, like Titan, has a fairly extensive atmospheric mantle.

Triton is closer to its primary than the Moon is to the Earth, and so looms large in the Neptunian sky; but the sunlight in those far-away regions is so feeble that Triton, despite its reflecting power, must appear pale and wan, and will be of little use as a source of illumination at night. It completes one circuit in

six days, and, like Phœbe and some of the smaller attendants of Jupiter, moves in a clockwise or 'retrograde' direction.

The second satellite, Nereid, was discovered by Kuiper in 1949. It is very minute – probably only about 200 miles across – but has a most unusual orbit, more like that of a comet than of a satellite. At its closest, it comes within a million miles of Neptune; at its farthest it recedes to over six million, and takes practically a year to complete one revolution. As a source of light, it must be completely useless; even when at its brightest, an observer on Neptune would see it only as a faint speck.

If Uranus is lonely and remote, Neptune is even more so. Despite the prospects of refuelling on Triton, it seems unlikely that any terrestrial space-craft will ever penetrate to such a distance; unless we master the art of travelling at phenomenally high speeds, a round trip to Neptune would take more than half a lifetime. It is hardly probable that any human eye will ever look from Triton or Nereid upon the sluggish, icy clouds which mask the outermost giant.

CHAPTER 15

Pluto

With the discovery of Neptune, the Solar System seemed complete once more. The wanderings of Uranus had been accounted for; the old observations of Flamsteed and Le Monnier had fallen into place, and all the irregularities which had so puzzled Bouvard were explained. Such was the general opinion for almost half a century. And then – very slowly, very slightly – Uranus started to wander again.

The differences between the predicted and actual positions were so small that they might have been due to observational errors; but it was possible that the cause was more fundamental, and Professor Percival Lowell, best remembered for his theories about Mars but also a mathematician of superlative skill, came to the firm conclusion that there was another planet waiting to be discovered. Accordingly, he commenced to work out just where it should be, much as Adams and Le Verrier had done in the case of Neptune.

Although the unknown planet was presumably beyond Neptune's orbit, and would therefore pull more strongly on Neptune than on Uranus, Lowell preferred to base his calculations upon the wanderings of the inner of the two giants. This was because Neptune's movements were much less well known. It had been discovered later, and had only completed a quarter of a revolution round the Sun since Galle had first recognized it in 1846. Two pre-discovery positions, made by the French astronomer Lalande in 1795, were available, but of rather dubious accuracy.

Lowell was well equipped. He had built his observatory at Flagstaff, in Arizona, specially for planetary work; and he started hunting in 1905, though his final calculations were not published until 1914. 'Planet X', as he called the unknown body, was thought to lie just under four thousand million miles from the Sun, moving in a rather elliptical orbit and completing one revolution every 282 years; and as the disturbances affecting Uranus were so small, Lowell thought that it must be a small planet

rather than a giant, with a mass perhaps six times that of the Earth.

Two years after his mathematical investigations had been completed, Lowell died, the planet still unfound; but meanwhile a similar investigation, based this time upon the movements of Neptune, had been carried out by another American astronomer, Professor W. H. Pickering. Pickering's results were in close agreement with those of Lowell, and in 1919 Milton Humason, at the Mount Wilson Observatory, commenced to search in the position indicated.

Despite the probable faintness of Planet X, Humason's task was less laborious than that of Challis seventy years before. Challis had to check each star visually, and the fact that he had no proper atlas prevented him from being the first to identify Neptune. Humason, however, could make use of photography.

If an area of the sky is photographed twice, with an interval of one or two days between the exposures, the stars will appear unaltered relative to one another; but a planet will be seen to have moved. All that need be done, therefore, is to check the two photographs, and see whether any 'star' has shifted.

To Pickering's disappointment, Humason was not successful, and Planet X obstinately refused to show itself. After a time the search was given up, but in 1929 astronomers at Lowell's observatory, Flagstaff, returned to it, armed with a new 13-inch refractor and an ingenious instrument known as a 'blink-microscope', used to examine exposed photographic plates. Clyde Tombaugh, then a young assistant observer and now one of America's most eminent astronomers, took charge of the search, and in January, 1930, he came across a suspiciously slow-moving object which soon proved to be the long-awaited planet.

Pluto, as it was named, was considerably fainter than expected, which is certainly why Lowell had not found it during his earlier searches. Humason's failure, however, was due to sheer bad luck. During 1919 he had actually photographed the planet twice, but one image fell upon a flaw in the plate, while the other was hopelessly masked by an inconvenient star. In all respects apart from brightness, Pluto fitted well with 'Planet X'. The distance was slightly less, the orbital eccentricity greater, the period of

revolution thirty years shorter; but on the whole, Lowell's forecasts had been pleasingly accurate.

Unfortunately, the discoveries which followed were most disconcerting. Pluto proved to be not only faint, but small and light. Instead of having six times the mass of the Earth, it began to look as though the Earth were actually the more massive of the two. The implications of this were far-reaching. A small

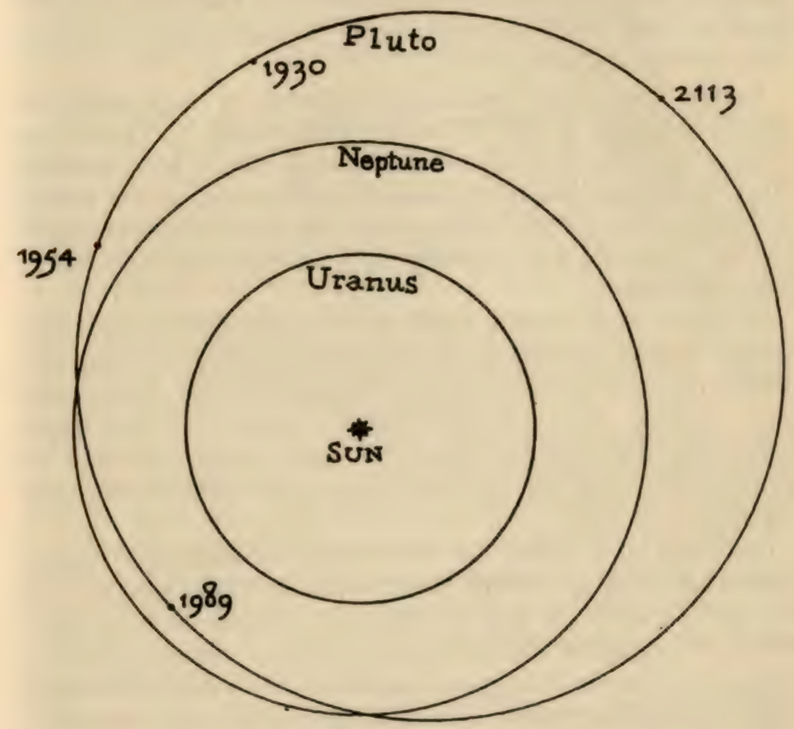


FIG. 32. The orbit of Pluto

body of this nature could not possibly have any measurable effects upon giants like Uranus and Neptune. Could the discovery have been due to pure chance, after all?

Further investigations showed that the orbit, too, has its peculiarities. When at its closest to the Sun, Pluto is actually closer-in than Neptune, though for most of its revolution period of 248 years it is much more remote. The orbit is shown in

Fig. 32. It will be seen that there is no danger of a collision with Neptune, since the path of Pluto is comparatively sharply tilted at an angle of 17°, and the two orbits never actually cross.

Altogether, Pluto proved to be a baffling little world. The most important thing was to find its mass, and, assuming a normal density, the best way of doing this was to measure its diameter. However, even the 100-inch Mount Wilson reflector was not powerful enough to show a measurable disk, and nothing much could be done until the great 200-inch instrument on Mount Palomar was available.

Kuiper made some preliminary measures in 1949, using the 82-inch telescope at the McDonald Observatory in Texas, and obtained a diameter of 6,400 miles, though with a large possible error. This would make the mass about 8/10 that of the Earth, so that the observed perturbations of Uranus and Neptune might just be accounted for, allowing for observational errors and a few coincidences.

In March 1950, twenty years after Tombaugh's original discovery, Kuiper and Humason, using the Palomar telescope, obtained the first accurate diameter measurements. The results were startling. Pluto proved to have a diameter of only 3,600 miles – less than that of Mars, not much more than that of Triton. It was thus inferior to any other major planet apart from Mercury.

Obviously, this threw the whole question wide open again. Assuming a normal density, Pluto would have only one-tenth of the Earth's mass, so that its effects on Uranus and Neptune would be negligible. On the other hand, it is stretching coincidence rather too far to suppose that two eminent mathematicians could obtain independent, accurate results based upon data that were completely erroneous.

If we accept the diameter measurements of Kuiper and Humason coupled with a mass sufficient to make Lowell's predictions valid, the density of Pluto will work out at nearly 10 times that of the Earth – over 50 times that of water. Here, again, we run into difficulties. Pluto would indeed be a remarkable body, made up entirely of very heavy materials, and with a tremendous surface gravity, far surpassing even Jupiter's – so that a man weighing 14 stone on Earth would weigh 66 stone

on Pluto! A pull of this kind would indicate a comparatively high escape velocity, and consequently an atmosphere made up of hydrogen, helium or neon (anything else would liquefy; the aphelion temperature of Pluto must be incredibly low, in the region of −400° F.). The atmosphere would be dense and low-lying, and would cause Pluto to reflect much of the feeble sunlight which falls upon it. Actually, Pluto seems to be a very poor reflector of light; the surface rocks must be almost black.

In any case, a high density of this sort seems improbable, to say the least of it. Is there any more likely solution to the puzzle?

When Pluto was young, it was presumably hot. As it cooled down, it lost most of its atmosphere, just as the Earth did, until it was left with a mantle made up largely of methane. As the temperature dropped still more, even the methane started to condense, collecting into a great liquid ocean covering vast tracts of the planet's surface. The rocks of Pluto are certainly very dark, but liquid methane would reflect light much more strongly; and it seems within the bounds of possibility that what Humason and Kuiper measured was not the full diameter of the planet, but merely the diameter of the ocean.

Of course, this is only a guess, and a development of an idea put forward by Dr. A. C. D. Crommelin, in 1936, who suggested that the apparent small diameter of Pluto might be due to the fact that the image of the Sun was reflected from a smooth surface – an idea supported by some practical experiments made in 1950 by Alter, Bunton and Roques of the Griffith Observatory and reported in Volume 63 of the Publications of the Astronomical Society of the Pacific.

Unless we regard the discovery of Pluto as a happy accident, which seems distinctly improbable, we must accept a much higher mass than is indicated by the small diameter measured by Kuiper; and at the present time, the problem remains unsolved. It is hopeless to try to observe any surface detail, as no telescope will show Pluto as much more than a faint yellowish speck of light; and we are unlikely to find out much more until the planet has been under observation for long enough to enable us to calculate the real mass with greater accuracy.

The one hope of doing this in the near future would be to

discover a satellite. The pull of Pluto upon an attendant would give us a key to the whole problem. Unfortunately, even a large satellite would be very difficult to detect at such a distance.

At the present time (1954), Pluto is still out beyond the orbit of Neptune; but it is drawing in to perihelion, and from 1969 to 2009 it will forfeit the title of 'the outermost planet'. It will be nearest to us in 1989, but subsequently it will retreat slowly but surely into the depths of space; by 2113 it will have reached aphelion, four and a half thousand million miles from the Sun. For fifty years or more on either side of that date it will be so dim that only the world's largest telescopes will show it, and our great-great-grandchildren will find it no easy task to observe Pluto at all.

Even if the main problems of space-travel are solved during the next few centuries, there is little chance of reaching Pluto; a round trip would take at least thirty years. However, we can at least make a last journey in imagination, and put ourselves in the position of an explorer standing upon Pluto at the time of its next aphelion – 160 years in the future.

The scene is utterly unlike anything we have pictured, even in our dreams. This time there are no choking clouds of ammonia or methane, no brilliant planet looming large in the sky and shedding its radiance across the rocks; no breath of wind stirs the thin, icy hydrogen atmosphere, and the whole world is bathed in deathly gloom. Pluto is a planet of eternal half-light. The Sun can be seen as an intensely brilliant point, but it is small and remote, and the shadows gather blackly around us.

High, rugged peaks tower to either side of us; through a gap we can make out a faint gleam, and we pick our way across the tumbled surface until we stand at the edge of a vast sheet of liquid. Clearly, the liquid is not water; Plutonian seas are made of methane, a chill, poisonous substance that would boil and evaporate upon almost any other world. No waves disturb it. It lives quiet, ghostly and dead, glinting strangely in the pale light.

What of other planets? We momentarily expect to see Neptune, close to the shrunken Sun; but before long we realize that even Neptune is too remote to be seen. With a powerful telescope we might catch a glimpse of it, but that is all.

Beyond all doubt, Pluto is the loneliest and most isolated world in the Solar System – cut off from its fellows, plunged in everlasting dusk, silent, barren, and touched with the chill of death. Nature seems to have passed it by, and it can never have known the breath of life. It marks the frontier of the Sun's kingdom.

CHAPTER 16

Beyond the Planets

So far as we know at present, Pluto is the outermost planet of the Solar System. Beyond it there is a vast gap, containing nothing but the incredibly tenuous interstellar gas and a few comets.

The first stellar distances were measured towards the middle of the last century, and it was found that the stars were so remote that our familiar unit, the mile, became meaningless; we had to fall back on the 'light-year', which has a value of just under six million million miles. Light takes only five and a half hours to travel out to Pluto; it takes over four years to reach the nearest star, so that even Pluto is relatively close to us when we consider the universe as a whole.

As a matter of fact, we have no proof that there is not another planet far out beyond Pluto. If it exists, it must be very faint, and even if it is the size of Uranus or Neptune its discovery must be largely a matter of luck; still, it may be there. Another suggestion is that Pluto itself, a world with many peculiarities both in itself and in its orbit, may not be a proper major planet at all, but either the brightest of a ring of trans-Neptunian asteroids or else a mere satellite of Neptune which has managed to give its parent the slip – in which case the true 'Planet X' of Lowell may still await discovery. What evidence have we either way?

Strangely enough, the strongest argument in favour of a trans-Plutonian planet is provided by those erratic wanderers, the comets. Comets are the stray members of the Solar System. Although sometimes of vast size, they are very flimsy and unsubstantial, made up chiefly of tiny rock particles and very tenuous gas; their masses are negligible, less even than that of a small satellite such as Nereid. Consequently, their orbits can be violently distorted by the action of the planets. There was even one comet, Lexell's, which became entangled in Jupiter's satellite system, and had its whole orbit and period of revolution round

PLATE XXVII. Pluto. Two photographs showing the motion of the planet in twenty-four hours (photographs, Mount Wilson and Palomar Observatories). Taken with the 200-inch Hale Reflector

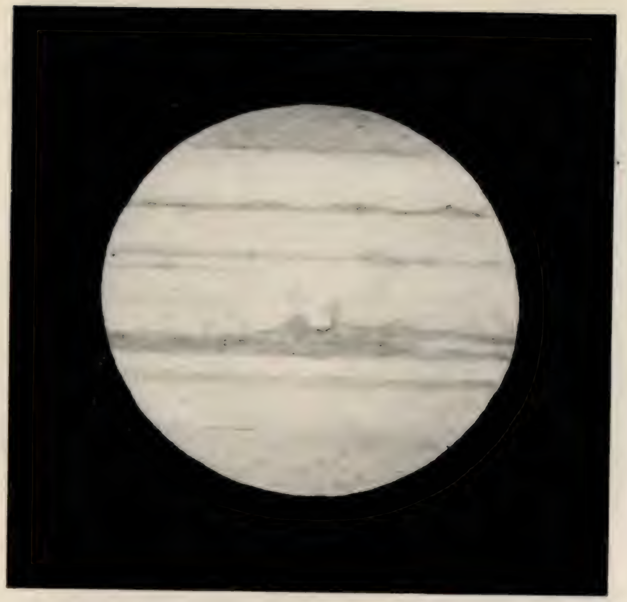


PLATE XXVIII. Drawing of Jupiter (1951, Aug. 30, 0h. 30m., $8\frac{1}{2}$-inch refl. ×350, Patrick Moore)

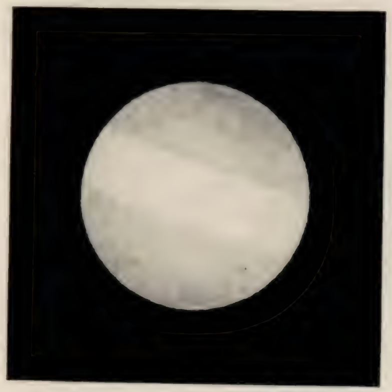


PLATE XXIX. Neptune (1953, Apr. 17, 60-inch refl. ×1,000 (Mount Wilson), T. L. Cragg)

the Sun completely changed in consequence. In general, the comets move in orbits much more elliptical than those of the planets; and it is a striking fact that over fifty of them have their aphelia (maximum distances from the Sun) at about the mean distance of Jupiter.

This is no mere coincidence. Jupiter's powerful pull is responsible, and to some extent the Giant Planet may be said to control its comet family. Saturn has a similar family of six comets, Uranus three, and Neptune at least eight. In 1928, Professor Pickering pointed out that there were sixteen known comets with their aphelion distances at about seven thousand million miles from the Sun, and this seemed to him to indicate the presence of a massive, remote body which he named Planet P. He considered that it was larger than Uranus or Neptune, and even went so far as to work out a preliminary orbit for it.

Following the discovery of Pluto by Tombaugh, in 1930, Pickering published a paper about his hypothetical planet P, and wrote as follows:

"When I first recognized its importance, from its comets, I mentally reserved for it the name Pluto, as the son of Saturn and the brother of Jupiter and Neptune; but unfortunately that small object now known as Pluto came round and perturbed Neptune some ten years before the leisurely P arrived and perturbed Uranus, and so received the name. Pluto should be renamed Loki, the god of thieves! A suitable name for P will now indeed be difficult to find when that planet is discovered."

Evidently Pickering was firmly convinced that Planet P really existed, and very recently Professor Karl Schütte, of Munich, has returned to the problem and come to similar conclusions. A by-product of Schütte's investigations has been the discovery of a group of five cometary aphelia at about the distance of Pluto, and these comets may form a true Plutonian 'family', though owing to Pluto's peculiar orbit and small mass it is difficult to be at all certain.

If Pickering and Schütte are right, the new planet will probably be found one day. Unfortunately, the comets give us no clue as to where it may be in the sky, and short of a mere chance discovery the only hope is to wait until the movements of Neptune and Pluto are known with sufficient precision for us to tell

whether they are, in fact, being disturbed by a remote body. We may have to wait for many years.

If Planet P exists, it must indeed be a dismal world. At a distance of seven thousand million miles, the sunlight would be drastically reduced; indeed, the Sun would appear so shrunken that to unaided eyes it would appear as nothing more than a brilliant point. No other planet could be made out, and an inhabitant of Planet P might well imagine that his was the Sun's only attendant.

Of course, we are being very insular in our outlook. The Sun is an ordinary star, quite unremarkable in every way; it is of average brilliancy and mass, and it would be most short-sighted to suppose that it is the only star in the universe to be encircled by a retinue of planets. Let us examine the question a little more closely.

The Sun is a member of the Milky Way system, more correctly called the Galaxy. The other stars visible at night-time are also members, and in fact the entire galaxy contains something like thirty thousand million stars, many of which must be almost exactly like the Sun. Moreover, there are millions of external galaxies, some of them probably as large as ours; and these too must contain vast numbers of stars similar to the Sun.

The external galaxies are terrifyingly remote. One of the nearest, the so-called Great Nebula in Andromeda, can be seen without a telescope as a faint, hazy patch of light, but at its tremendous distance of something like 1½ million light-years we can only make out the most luminous stars in it; a star of normal luminosity, such as the Sun, would be far too faint to be detected. Consequently, it is quite hopeless to even think of searching for planets in other galaxies. We need not be depressed at this; our own Milky Way contains a great many stars which we may reasonably expect to be accompanied by planetary systems.

Unfortunately, there are a great many uncertain factors. Until we know for certain just how the planets were formed, it is hard to tell whether they would have arisen even had the Sun been a very different type of star. However, the general argument is unaffected. The Sun is no freak. Similar stars may well be surrounded by similar systems of planets.

The trouble is that we shall never be able to observe them directly, owing to their faintness and remoteness. The Galaxy covers a vast area, and even the distance between Earth and Pluto becomes negligible by comparison. If we take the Sun as our centre, and draw a circle in space with a radius of eleven light-years, we shall not trap many stars inside; we shall find only fourteen, eleven of them far inferior to the Sun in size, mass and luminosity. Only three are conspicuous in the night-sky – Sirius, the brilliant Dog-Star; Procyon, in the Little Dog; and the bright southern star known properly as Alpha Centauri, but which wartime R.A.F. navigators christened 'Rigel-Kent'.

Planets have no light of their own. They have to borrow their glory; and if Jupiter, giant of the Solar System, happened to circle round even the nearest star, it would be far beyond the reach of the most powerful telescopes we are ever likely to construct. However, it might make its presence felt by its gravitational pull, and one of the nearest stars, 61 Cygni, does actually seem to have a massive planet revolving around it.

61 Cygni – so called because it lies in the constellation of Cygnus, the Swan, and was No. 61 in a famous catalogue drawn up about three hundred years ago by Flamsteed – is just visible to the unaided eye, and achieved fame in 1838, when it became the first star to have its distance accurately measured. We know now that it is $10\frac{9}{10}$ light-years away, corresponding to about 64,000,000,000,000 miles, and that it is a twin system, made up of two stars revolving around their common centre of gravity in about 700 years. The brighter component, A, has about 1/19 of the Sun's luminosity, while B, the other component, is appreciably fainter.

In 1944, Dr. K. A. Strand, of Sweden, announced that in addition to its orbital motion round the centre of gravity of the system, 61 Cygni B was 'wobbling' perceptibly in its path. The disturbing body could not be seen visually; it was much too faint for that, and as the 'wobble' produced was small, Dr. Strand deduced that the body must be of low mass. He worked out that it was about 15 times as heavy as Jupiter.

Stars with low masses such as this do not exist; they can never have been formed, and therefore the disturbing body is not a star. It must be a planet. Probably it is a cold, dark globe,

dependent for its light and heat entirely upon the feeble sun around which it moves. It may, of course, have cooled down less than Jupiter or Saturn, and retain a certain amount of inherent light; but there seems no doubt that it is planetary and not stellar in nature.

One or two other extra-solar planets have been suggested. The star 70 Ophiuchi is believed to have a companion whose mass is only 12 times that of Jupiter. We have at last proved that other planetary systems exist, though not for many centuries yet may we find out how frequent they are.

As we can only detect these extra-solar planets by their pulls, we are confined to the most massive ones. A small body the size of the Earth, or even Neptune, could have no measurable effect upon the motion of even the lightest star.[1] This must not be taken as evidence that other planets similar to the Earth do not exist; on the contrary, it seems almost certain that they do.

Consider the bright star Procyon, in the Little Dog, which shines down from winter skies above the shoulder of Orion. It is over five times more luminous than the Sun, and a mere 10½ light-years away, so that it is even closer than 61 Cygni; why should it not have an Earth circling round it? The inhabitants of this other Earth would be warmed by a sun more splendid than ours, whiter, hotter, and probably more active, and accompanied by a smaller but very heavy star; in their night-skies they would be able to make out a very ordinary yellowish star, far inferior to their own. How could they tell that this star is the ruler of nine planets, one of which is peopled by intelligent beings who have already solved many of the mysteries of nature and are almost ready to take their first leaps into the abyss of space?

One thing is certain. We may eventually detect other Earths circling round other stars, but we shall never be able to reach them. In our own Solar System, we may eventually be able to travel at will; other solar systems are for ever beyond our reach. For the sakes of intelligent beings living there, if they exist, this is probably just as well!

[1] Mass is the important factor, not size. Stars are known which are considerably smaller than the Earth, but these are peculiar objects known as 'White Dwarfs', of great mass, low luminosity, and incredible density—a matchboxful of white dwarf matter would weigh hundreds of tons. Procyon, like Sirius, is accompanied by a white dwarf companion.

CHAPTER 17

Life on the Planets

We know that the Sun is a normal star; yet from our own point of view, the Earth is not a normal planet. It is unique inasmuch as it is the only world in the Solar System upon which we could survive. Of the other planets, only Venus and Mars have bearable temperatures; Venus has the wrong sort of atmosphere, and the Martian air is too thin.

Once again, however, we are being insular in our outlook. A polar bear would soon die if taken to the middle of the Sahara Desert, while a camel would be equally unable to cope with conditions in the Arctic Circle; each has adapted itself to its particular surroundings. Is there any reason why beings on other planets should not have done the same?

Before coming to any definite conclusions, let us pause to consider just how living creatures are built up. We cannot say just what 'life' is; we cannot create it (though, unhappily, we can destroy it with alarming ease), and neither can we tell how the first primitive creatures came into being. We do know, however, that all living structures depend upon carbon, because atoms of carbon have a remarkable property of building up complex atom-groups of the right type.

There are only 92 different kinds of atoms in the universe, and each is peculiar to its own 'element'. Other elements have been manufactured in recent years, but they are unstable, and probably do not occur in nature, so that we can be perfectly sure that even the remotest stars are made up of substances familiar to us.[1] The only other atom which possesses something like the powers of carbon is the atom of silicon. All the rest are quite incapable of behaving in such a way. Our knowledge of physics,

[1] Some people find it difficult to believe that every particle of matter in the universe is made up of combinations of only 92 elements; but we can draw an analogy from our ordinary experience—the symphonies of Beethoven, the lyric dances of Grieg and the melodies of Sullivan are all formed by different combinations of the twelve fundamental notes of the octave.

therefore, seems to tell us that living things anywhere in the universe must depend either upon carbon or upon silicon.

Carbon-based life must be essentially similar to our own; there is no room for doubt upon that score. Silicon-based life does not occur on the Earth, and if it occurs anywhere it is certainly of an alien form. However, there is no evidence that it does exist, and a great deal of indirect evidence that it does not. In short, we are justified in thinking that all kinds of life in the universe are fundamentally similar to our own.

Naturally, life is likely to assume diverse forms. Intelligent Martians might not resemble men at all; the human body, as we all know to our cost, is a badly-constructed piece of mechanism, with innumerable weak points, and Nature's experiments on other planets may have been more successful. All we can say is that if life exists on Mars or anywhere else, it is probably carbon-based. This makes it likely that the essentials for the appearance of life are a fairly equable temperature, an atmosphere of sorts, and means of nourishment.

Of course, we may be entirely wrong. Somewhere out in the system of 61 Cygni or Alpha Centauri there may be a planet upon which live bright green men who coo like pigeons and are made of pure uranium – but it does not seem very likely, and we must make a reasonable interpretation of what evidence we can collect. 'Life', so far as we are concerned, must mean 'life as we know it'.

As we have seen, there must be many Solar Systems in the universe, some of them containing worlds which are almost replicas of the Earth. Life has arisen on our planet; therefore it will probably arise anywhere where conditions are similar, and it is short-sighted to suppose that we are members of the only thinking race in all the galaxies. But we shall never be able to obtain definite evidence either way; and in addition to stipulating the kind of life we are looking for, we must confine our search to our own Solar System.

The temperature qualification seems to rule out nearly all the planets, without delay. Jupiter and its fellow-giants, as well as Pluto, are too cold; Mercury too cold on one side and too hot on the other – though there may be a loop-hole here if we remember the twilight zone between the two regions. Extreme heat breaks

up the carbon atom-patterns and destroys all living cells, while bitter cold is equally effective in destroying the vital force; and if we add Mercury to our list of rejects, on the score of virtual airlessness, we come back, as always, to Venus and Mars.

Our ideas have developed very rapidly during the last hundred and fifty years, and it is surprising to learn that Sir William Herschel, discoverer of Uranus and first president of the Royal Astronomical Society, was quite convinced that there were people living in a warm, comfortable region beneath the fiery surface of the Sun.[1] We now know, however, that the intense solar heat breaks up not only the delicate complex atom-patterns, but also atomic groups which are capable of resisting temperatures which to us would be intolerable.

However, it must be admitted that there is no theoretical bar to the existence of higher forms of life upon either Mars or Venus; we may consider it unlikely, but we cannot reject it out of hand. It is almost certain that Mars possesses plants, at least – and where plants can exist, it would be no surprise to find animals and even intelligent beings.

The crux of the whole matter is that life is remarkably good at adapting itself. Plants exist in the most unlikely places, and some lichens eke out a livelihood in the polar regions in positions where the temperature hardly ever rises above freezing-point. Deep-sea fish thrive in regions where the overlying water exerts a tremendous pressure – indeed, they die quickly if brought to the surface. A fish-scientist might well wonder how those strange two-legged creatures could exist out of the water, under conditions of what would be, to him, negligible pressure.

Even higher animals mould themselves according to environment. Whales soon lost their now-useless legs when they returned to the ocean after their brief career as land-mammals; the zebra has developed protective stripes, and when the ant-eater first discovered his liking for live ants he set himself to develop a tough coat which would enable him to raid their nests

[1] Weird ideas of this sort still linger on. In 1953 there was a lawsuit between the German Astronomische Gesellschaft and a solicitor named Büren, who argued that the Sun was habitable and had vegetation on it. The legal court at Osnabrück decided in favour of the Astronomische Gesellschaft, but failed to persuade Herr Büren that his ideas were somewhat out of date!

unscathed. Even men are adaptable. The Esquimau is quite comfortable in the Arctic, but the African negro would soon die if taken to winter in an igloo.

In its vigorous youth, Mars was probably a world with dense atmosphere and abundant moisture. As the air leaked away and the water dried up, is it unreasonable to assume that Martian life adapted itself to the changing conditions?

Our knowledge of life is so small that it is pointless to speculate as to what the 'Martians' might be like, if they existed. The general tendency of fiction-writers, even those of the calibre of H. G. Wells, is to turn them into monsters spreading death and destruction in their wake, but there seems little justification for such an idea; indeed, we may reasonably hope that other intelligent races, if they exist, have not developed our own unpleasant tendencies.

It would be interesting to try to communicate with intelligent beings on Mars. A scheme was once proposed for tracing out vast geometrical designs in the Sahara Desert, in the hope that the Martians would see them and reply in similar vein – mathematical designs must be universal, as the universe itself is nothing more than a vast mathematical machine – but it was never put into effect. Professor Lancelot Hogben has even worked out a possible means of making the Martians understand us when we first meet; frequent attempts have been made to call up Mars by radio, but so far the beings on the Red Planet have not been courteous enough to reply, which indicates either that they do not exist, that their wireless is not sufficiently advanced to pick up the messages, or that they know enough about us to keep us at a safe distance!

Conversely, Martians have from time to time been said to be trying to visit the Earth. A Russian 'scientist' suggested in all seriousness that the Siberian meteorite of 1908 was no meteorite at all, but a visiting space-ship; and in 1938 thousands of people in the United States were affected by mass hysteria as a result of a misleading broadcast version of Wells' *War of the Worlds*, which they took for an actual news bulletin. More recently, we have had the flying saucer craze. An incredible amount of nonsense has been written about these objects, not only by newspaper reporters but also by popular scientific writers who should

certainly know better. However, a recent book by Dr. D. H. Menzel has pricked the bubble once and for all. Flying saucers are neither space-ships nor terrestrial aircraft; they are natural phenomena.[1]

Rather reluctantly, we must conclude that intelligent life on Mars or Venus is distinctly improbable, while elsewhere in the Solar System conditions are even less favourable. If the planets are to be peopled at all, it must be through our agency. What are the prospects of colonization?

There should be little difficulty in setting up bases on the Moon and Mars once the principles of space-flight have been mastered, but surviving there in the open, without cumbersome protections such as airtight domes or insulating suits, is another matter. We cannot deliberately alter our physical characteristics; we have no idea of how to adapt our lungs to breathe the thin Martian air, and although we may learn enough during the next thousand years to make some attempt at it, there are obvious difficulties. The only alternative is to adapt the planets to our own requirements.

Providing Mars with a breathable atmosphere seems a truly Herculean task. We might improve the oxygen content if we could persuade enough plants to live on the surface, since plants provide oxygen; but increasing the atmospheric density is certainly beyond our powers. Venus is perhaps more promising. There is enough atmosphere there, even though it is of the wrong kind; and when we have increased our knowledge a hundredfold, there may be a certain amount of hope.

But we are verging on fantasy. Our home is the Earth; we are creatures of the Earth, and other worlds may not be meant for us. We have almost sufficient knowledge to make our first trips into space, but we are no more masters of the Solar System than a queen bee is mistress of our own planet.

[1] In 1950 I was called up by the news editor of a famous London daily paper and asked for my views about a report that a flying saucer had landed in Mexico, crashing into the mountains and killing the sole occupant, a red-haired man only two feet high. It was subsequently found that the report had been circulated by the manager of a local hotel. Even if no scientist, he was at any rate a good psychologist.

CHAPTER 18

Voyages to the Planets

The art of flying has intrigued men ever since the early days of human history. The legend of how Dædalus and his son Icarus escaped from Crete by using artificial wings is thousands of years old, and there are many stories through the ages of men who managed to fly by artificial means. Some of these stories are probably founded on fact, inasmuch as short 'hops' seem to have been made now and then; but the first proper flight was made on October 15, 1783, by a young French naturalist named De Rozier, who went up in a balloon.

Balloons are difficult to control, and are bound to remain largely at the mercy of the winds; the true conquest of the air did not begin until well over a century after De Rozier's ascent, when Orville Wright made the first flight in a power-driven aeroplane. It is rather surprising that subsequent developments have been so rapid. In only 50 years, aircraft have changed from the primitive machines of Wright and Blériot to the giant high-altitude liners now so familiar to us all; and, in fact, the mastery of the lower atmosphere is now approaching completion. Naturally, we turn next to that greater problem, the conquest of outer space.

Again we find that the idea is not new; Lucian, an old Greek writer, wrote a highly entertaining story about a trip to the Moon as long ago as the 2nd century A.D., and in 1638 an English bishop named Godwin published a famous book upon the same theme. During the present century, the trickle of 'science fiction' has become a flood. The main difference between old and new stories of this type is that the more reputable modern writers make an attempt to keep as closely as possible to scientific facts, while the older authors were in no position to do so.

Perhaps the first plausible interplanetary story was Jules Verne's *From the Earth to the Moon*, in which he sealed up his adventurers in a projectile and shot them off from the mouth of a vast cannon. Unfortunately, he overlooked two vitally im-

portant facts; air-resistance would destroy the projectile even before it had left the mouth of the cannon, and in any case no human frame could stand up to so tremendous a jerk. Oddly enough, H. G. Wells returned to the space-gun idea in *The Shape of Things to Come*, the first of the interplanetary films;[1] but Wells was a good enough scientist to realize that the whole idea is unworkable – though it is possible that in the far future, space-guns may be used to fire non-fragile materials away from airless worlds with low escape velocities.

The other famous interplanetary story, Wells' *First Men in the Moon*, makes no attempt at accuracy. Wells was intent upon telling a good story (which he could do superlatively well), and he was fully aware that his 'Cavorite', special material which shielded anything above it from the effects of gravity, is a scientific absurdity.

The greatest obstacle to space-travel is, of course, the pull of the Earth. By starting off with a jerk at escape velocity, seven miles a second, we could leave our world behind for ever; the crippling drag of the Earth would trouble us no more, and a properly-aimed projectile might well end its career upon the rocks of the Moon. Unfortunately, there are many difficulties about working up to such a speed. There is no need to reach escape velocity at all if we can manage to go on applying power all the time, but this would be hopelessly uneconomical; no matter what fuel we used, no space-craft could hope to carry enough even for the outward journey.

We can consider that we have left the Earth's effective air-mantle once we have reached a height of some 150 miles, and in a way this is an advantage. Air is a resisting medium, as can be demonstrated by cupping one's hand and swishing it downwards. It also means, however, that none of our ordinary flying machines will work. The balloons of Montgolfier and De Rozier, the aeroplanes of Wright and the jets of Sir Frank Whittle are equally useless. Balloons depend upon air for their lift, aeroplanes need air for their propellers to grip, and jet motors are dependent upon oxygen drawn from the atmosphere. Some other source of power must be found; and at present the best bet is

[1] More correctly, the first to be produced in English. It had been anticipated by one or two German films upon the same theme.

the rocket, which is at its most efficient in total vacuum and is not confined to low altitudes and comparatively modest speeds. This is because the power of a rocket depends entirely upon what is known as the 'principle of reaction'.

Imagine a sleigh lying upon smooth, frictionless ice. If a boy stands on one end of it, and kicks off, the boy will move in one direction and the sleigh in another. If the boy and the sleigh have the same mass, their speeds will be equal; if the boy is the lighter, he will move the faster. The important point about this simple experiment is that the boy and the sleigh would move in just the same way even if they were placed in total vacuum.

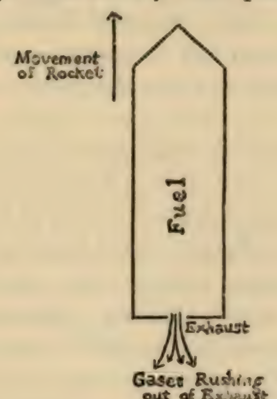


FIG. 33. Principle of the rocket

As Newton discovered, any action has an equal and opposite reaction.

Now consider a simple rocket, of the type shown in Fig. 33. It consists of a tube filled with some sort of explosive, such as gunpowder, and a hole or 'exhaust' drilled at one end. When the explosive is fired, hot gases are generated, and try to expand in all directions. The only way they can escape is by the exhaust, and so they rush out in a concentrated stream; in doing so, they kick against the rocket tube, and send it off in the opposite direction. The fundamental principle is exactly the same as in the case of the boy and the sleigh; the gases play the part of the boy, and the rocket tube is the sleigh.

So long as the gases keep streaming through the exhaust, the

rocket will continue to accelerate. When the fuel has burned out, the rocket will climb on until it has expended its initial impetus, finally falling back to the ground. All of us have seen rockets of this type on November the Fifth, though probably it has occurred to very few of us that developments of such toys will lead us eventually to other worlds.

It is perfectly clear that no gunpowder rocket can possibly be refuelled in flight. The instructions printed upon the side say, briefly and concisely, "Light the blue touch-paper and retire immediately", and disregard of this order would be likely to result in a voyage to the local hospital rather than to Mars. Solid fuels are non-controllable and, incidentally, inefficient; and this is why devices such as postal rockets and rocket cars have never been satisfactory.

Liquid fuels are much more promising, and a rocket drawing its power from petrol and liquid oxygen was developed by Dr. Robert Goddard, of the United States, between 1919 and 1926. Naturally, this was a comparatively complex affair; there had to be pumps, storage tanks, ignition mechanism, and a firing chamber for the burning to take place. The original 'rocket' had, in effect, been superseded by the 'rocket motor'. Nevertheless, the underlying principle remained the same, and the speed of the rocket depended upon the 'kick' given to it by the expanding gases as they streamed out of the exhaust.

It would be difficult to over-estimate the importance of Goddard's work, and the firing of his first liquid-fuel rocket, in 1926, may be said to mark the start of a new age – the age of space travel. Interplanetary flight became at once worthy of serious consideration, and within a few years flourishing rocket societies had grown up in most large countries of the world.

The choice of objectives was limited. There has never been any serious doubt that the Moon will be the first celestial body to be visited, as it has certain obvious advantages; it is comparatively close (only as far off as ten times round the terrestrial equator), and we know a great deal about surface conditions there, though it is true that our knowledge is far from complete. On the other hand, it is virtually airless, and is likely to be an uncomfortable world. The other possibilities are Mars and Venus. Venus is a hundred times as distant as the Moon, Mars

even more remote; but, oddly enough, sheer distance is not so important as might be thought at first sight. This is because nearly all the journey would be accomplished in what is known as 'free fall'.

If a bullet is fired from a rifle, it will gradually lose speed and fall back to earth. This is partly because it is being constantly braked by air-resistance, and partly because it is being affected by a powerful gravitational field acting in one direction only. Neither of these limitations applies in space; so what would there be to stop the bullet moving on indefinitely? Nothing. It would in fact be in a condition of free fall, and would therefore have no apparent weight.[1] This idea of free fall is of fundamental importance in the new science of 'astronautics', and it is now clear why it will not be much more difficult to reach Mars than the Moon from considerations of distance only – though associated problems will, of course, be much greater.

A parachutist who bales out from a high-flying aircraft experiences a momentary sensation of free fall, though he is of course braked by air resistance and soon checks himself by pulling on his rip-cord. Not long ago, two mice and a monkey named Albert were placed in a rocket and fired up into the stratosphere, with an automatic camera to record their reactions; and all three returned quite unhurt, which seems to indicate that the condition of free fall is not dangerous to living organisms. The antics of the mice, floating in a condition of weightlessness, were most interesting, but both were lively enough when picked up; Albert can have only vague recollections of his eventful trip, as he had been placed under an anæsthetic, but he too was none the worse.[2]

However, no space-craft can remain for long in free fall unless it first breaks free from the persistent pull of the Earth. To break free, it must attain escape velocity, and intensive research carried out during the 1939-45 war showed clearly that no chemical fuels would provide sufficient power for this – a conclusion which Goddard had reached independently many years before. German V2s, and subsequently American rockets, could soar high into the stratosphere; but they could never move fast enough to leave the Earth permanently, and if interplanetary flight was to be accomplished some new idea would have to be put forward.

[1] Strictly speaking, our feeling of weight upon the Earth's surface is not because we are in a gravitational field, but because we are resisting the Earth's attempt to pull us downwards to the centre of the globe. Out in space, we would not be resisting anything; and therefore the sensation of weight would vanish completely.

[2] It is interesting to remember that even before De Rozier's first ascent, a balloon flight had been made by a sheep, a cock and a duck. The only casualty was the cock—which was kicked by the sheep before take-off.

In 1949, a rocket took off from the research station at White Sands, in New Mexico, carrying an unusual passenger – a smaller rocket. As soon as the first rocket had exhausted its fuel supply, it parted from its companion, and eventually fell back to earth; the second rocket continued the journey under its own power, with the double advantage that when it started its own motors it was already above much of the resisting atmosphere, and had been provided with considerable initial velocity. The result was that it reached a record altitude (250 miles). This is the principle of the 'step-rocket', and is the way in which the interplanetary problem will probably be solved.

There is no need to confine ourselves to two steps. The engineering problems connected with multi-step rockets will be formidable, to put it mildly, but theoretically such rockets can be made; neither is there any theoretical limit to the speed available. Each successive 'step' will go faster than the last.

A step-rocket will be large, expensive and cumbersome, and the whole step principle may be dispensed with if we can only harness the power of the atom. Unfortunately, there is no immediate prospect of doing this. We can release a large amount of energy with one big bang, as has been forcibly demonstrated; but we have no idea of how to control it, and in any case all atomic generators have to be so drastically screened that they are bound to be very heavy. In the far future, the atomic rocket may well come into its own; but it would be most unwise to place any real faith in our ability to tap unlimited sources of power.

There is one other way in which we can avoid using step-rockets for the lunar or Martian voyage. We know that the main trouble is the pull of the Earth; therefore, can we start our journey from anywhere else?

It is more than possible that the first travellers to Mars will

take off from the Moon, where there is no air-resistance to reckon with and the escape velocity is comparatively low. But the Moon itself has to be colonized first, and it may be preferable to build an artificial space-station just outside the effective limit of the Earth's atmosphere – say at an altitude of about 1,000 miles.

If a rocket could be fired out to this distance, and then given the right amount of 'sideways' thrust at the right moment, it would fall into an orbit round the Earth, and continue circling indefinitely. There would be no chance of its falling down, since it would be in a condition of free fall, and it would in fact become a satellite of the Earth in the same sense that the Moon is. Other material could be fired into the same orbit, and gradually a complete station could be assembled out in space.

The original rocket destined to form the nucleus of the future space-station would be moving fast enough to complete one revolution of the Earth in something like two hours, but to a second rocket moving in the same orbit it would appear stationary. Two cyclists riding abreast do not appear to move relative to each other, and we must remember that the speed of a rocket in its orbit is only the speed relative to the Earth. Moreover, nothing would have any apparent weight (if we disregard the pull of the rocket's own body, which would be inappreciable), and building the space-station would not be an insuperable task for men in specially designed suits. Two or three men could handle a steel sheet which on Earth would weigh tons.

The advantages of a man-made world of this kind are obvious. The Station would already be moving round the Earth at circular velocity, which simplifies the problem of taking off from other planets; all a space-ship would have to do is to increase its speed slightly from circular to escape velocity, which presents no problems at all. If the first interplanetary travellers start their journey from the Earth's surface, in a step-rocket, they will have to undergo a short period of extreme discomfort as the rocket accelerates, pressing its occupants down with a force of several gravities until even breathing becomes difficult; but taking off from an artificial satellite would be much less disagreeable.

It follows from this that the true interplanetary craft would not have to be winged or streamlined, as it would spend its entire life in space and would never enter the Earth's atmosphere at all. Our popular idea of a space-ship as sleek and tapering must be abandoned, though the transit-rockets between Earth and Station would of course be built upon this design.

When a new venture is proposed, there are always plenty of people anxious to prove that it is ridiculous, useless, and in any case impossible. Even during the present century, Professor Simon Newcomb, one of America's leading astronomers, proved conclusively that flying in a heavier-than-air machine was out of the question; and doubtless Sir Edmund Hillary set off for Everest with the full knowledge that his ambition was regarded in a similar light. It would be folly to underestimate the risks which the first space-travellers will run, but most of the 'fatal difficulties' between them and success prove to be far from fatal.

Once the space-ship has escaped from Earth, and is in the interplanetary void on its way to another world, it and all things inside it will be experiencing free fall. This means that nothing will have any apparent weight, and the immediate results will be curious indeed. A pencil held out and released will not fall; it will remain poised in the air, and the slightest push will send it wandering across the cabin until it rebounds from the opposite wall. Water will not pour out of a bottle; in fact the only way to drink comfortably will be by using a straw. There is no need to elaborate upon the queerness of all this, but the main question is – will it hurt us?

Medical opinion seems to be unanimous that it will not. The most important of all bodily organs, the heart, does not depend upon gravity, and, in fact, lessened gravity conditions may be beneficial to heart sufferers; in the remote future, there may well be a hospital on Mars or the Moon, perhaps even out in space on an artificial satellite. The balance mechanism of the inner ear may be upset, but on the whole there seems no reason to suppose that zero weight will be particularly uncomfortable. More than that, nobody can say at the moment – apart possibly from Albert the monkey.

Air can be taken on board. Storage presents no insuperable difficulty, particularly as we can dispense with most of the nitrogen – which makes up over three-quarters of our normal air mixture – and save space for the life-giving oxygen. Food and

drink can also be taken, though a journey to Mars or Venus will take months and the diet on board the vessel will be rather monotonous.

However, space is not without its perils, and perhaps the worst is that of harmful radiations. The undesirable ultra-violet rays sent out by the Sun are cut off by the layer of ozone in our atmosphere; once we emerge, we shall be exposed to the full force of the ultra-violet barrage, and shall have to screen ourselves. Even more serious are the cosmic rays, about which we know very little. Probably we shall be able to protect ourselves from these also, but at the moment it is not at all clear how serious the cosmic ray danger is.

Meteors, small pieces of rocky material circling round the Sun, are also potentially dangerous. Most of them are very small indeed, no larger than sand-grains; but a collision with a meteor the size of a pea, travelling at high velocity, would be far from pleasant. In most cases the crew of the space-ship would have time to repair the damage before enough oxygen escaped to render them unconscious; but if we are right in supposing that the true Space Age will begin within the next couple of centuries, we shall have to expect occasional tragedies on this account.

So far, we have only considered outward journeys from the Earth to other planets. Obviously, however, the return journey will be just as important, and we must carry enough fuel to enable us to take off again on the homeward trip. Returning from the Moon will be comparatively easy, with no air-resistance and an escape velocity of only $1\frac{1}{2}$ miles a second; moreover, the voyage between Moon and Earth, or Moon and space-station, will be of comparatively short duration (not more than 100 hours). Mars is another celestial lightweight, but even so it is probable that the first voyagers will make use of the two tiny satellites, Phobos and Deimos, which may be considered as perfect natural space-stations. Venus presents more problems. The mass, and hence the escape velocity, are very similar to ours, and in any case we know so little about the surface conditions that it will be prudent to study the planet carefully, both with manned and unmanned craft, before risking an actual landing there.

Of other worlds, we can say little as yet. Some, such as Mercury and the larger moons of Saturn and Jupiter, may be reached within the next few hundred years; but it would be foolish to make any hard-and-fast predictions.

It is unfortunate that so many over-optimistic forecasts have been made during the last few years. We sometimes read that space-stations will be built by 1965, the Moon colonized by 1980, and Mars and Venus thoroughly explored by 1999. This is arrant nonsense. Our knowledge is still growing, but it is still inadequate; and although the first lunar explorers may well set foot on the Queen of Night before the dawn of the twenty-first century, there is little hope of any man of 1954 surviving for long enough to witness the first flights to Mars or Venus.

We need not be discouraged, for we, too, can play our part in the great adventure that is to come. Our task is to find out as much as we can about the worlds we hope to reach. The tiny, pale disks of the planets, shining into our telescopes across millions of miles of space, throw down a challenge to us; they give us the hope of a key to their hidden secrets. If we can solve at least some of these secrets, we shall be doing much to help those descendants of ours who will eventually push the frontiers of Earth far into the void.

APPENDIX I

Observing the Planets

A great deal of pleasure can be had from studying the night-skies with binoculars, or with an ordinary naval telescope. For serious work on the planets, however, a proper astronomical instrument is naturally essential, and telescopes are expensive. Fortunately there are ways and means round this difficulty.

There are two main types of telescope, the refractor and the reflector. Each type has its own advantages and disadvantages. The refractor is employed for ordinary terrestrial use, and is therefore more familiar; it collects its light by using a lens, or 'object-glass', which brings the light to focus near the bottom of the tube, where the image is magnified by a second lens – or, more correctly, a combination of lenses – known as an eyepiece. Astronomical refractors differ from terrestrial ones in an important respect; they give an inverted image, because the extra lenses put into the naval telescope to correct for this are left out. Each time a light-ray passes through a lens, it becomes slightly enfeebled, and though this is of no importance in everyday use it is very important indeed when observing a faint celestial body, from which every scrap of available light must be utilized. All astronomical pictures and diagrams are thus oriented with the south at the top.

The reflector dispenses with the object-glass, and collects its light by means of a polished, suitably-shaped mirror. In the usual form, invented by Sir Isaac Newton and therefore known as the Newtonian, the light passes unchecked down the tube – which may be a skeleton, not a closed tube at all – falling upon a mirror at the bottom. The light-rays are then reflected back up the tube and concentrated upon a smaller mirror near the upper end. This smaller mirror, or 'flat', is tilted at an angle, and directs the light-rays to the side of the tube, where they are brought to focus and magnified in the usual way.

There have been many arguments about the relative merits of

the refractor and the reflector. Reflectors are cheaper, and more comfortable to use; moreover, any reasonably skilful amateur can produce his own mirror, whereas lens-making is beyond any but the experienced professional. On the other hand, reflectors are more trouble, as they need a good deal of adjustment and the mirrors require periodical attention.

The resolving ability of a telescope is determined by the diameter of the object-glass (for a refractor) or main mirror (for a reflector). Inch for inch, the lens has the greater power. A 3-inch refractor is quite large enough for useful work, at least on the Moon, and is the beginner's favourite instrument; however, no reflector under 6 inches aperture is of much real use, though it will show some pretty sights.

Trouble is often experienced because of poor mounting. Many small refractors are sold on table 'pillar and claw' stands, which look nice and are cheap, but are unfortunately quite useless. They can never be made properly steady, and a telescope which quivers at the lightest footfall or breath of wind will produce a planetary image which seems to dance a wild waltz in the heavens.

If you purchase a small refractor on a pillar and claw, the best course is to consign the mounting to the dustbin and invest in a tripod. A heavy wooden camera tripod will do quite well, and will provide the stability needed. Reflectors are not quite so easy to mount, but present no real difficulties to anyone with a certain amount of manual skill.

In general, refractors over 4 inches aperture and reflectors over 6 inches need a permanent site, preferably something in the nature of a concrete pillar; but this is not a hard-and-fast rule, and larger telescopes, particularly reflectors, may be made reasonably portable.

Mounting the telescope 'equatorially', i.e. on a revolving axis directed towards the celestial pole, is a great help; and properly-equipped observatories are provided with clock drives, which move the telescope steadily and compensate for the rotation of the Earth. Fitting a clock drive requires some specialized knowledge, and an alternative is to have manual slow motions – rods which can be twisted to move the telescope very slightly. Even these, however, are unnecessary for small instruments. My own

3-inch refractor used to have slow-motion rods, but I dismantled them, as I found that they were more trouble than they were worth.

The usual obstacle to a permanent observing site is lack of sky-space. It nearly always happens that an inconvenient tree or house is so placed that it covers a vital area. A small tree or bush can often be reduced or eliminated by judicious (sometimes surreptitious) chopping, but a massive oak is another matter, while even the most enthusiastic amateur astronomer is apt to have qualms about removing the top storey of his house. If a permanent site has to be selected from a number of unprepossessing possibilities, it is best to retain as much of the southern sky as possible. Planets are best placed when southerly, as they are then at their highest, and it is useless to observe a planet when it is low down near the horizon. (Mercury and Venus, of course, have their own way of behaving.)

It often happens that an enthusiastic beginner purchases a small refractor on a pillar-and-claw stand, perches it precariously upon a rickety table, pokes it out of (or through) a window, and hopes to see something startling, such as a Martian canal. He will be disappointed. Turbulence due to the meeting of the warm air indoors and the cooler air outdoors is invariably sufficient to disturb the image so much that nothing will be seen except a shimmering, shapeless blob of light. Moreover, only an expert contortionist could find a comfortable observing attitude with his telescope aimed through a window, and altogether the procedure is not to be recommended.

Meteorological conditions are all-important. Many people are surprised when they first learn that no optical telescope can penetrate cloud; indeed, the thinnest layer of cloud is nearly always fatal to the sharpness and steadiness of a planetary image. Thin mist, however, is not so disastrous. Misty conditions are often accompanied by steadiness of the atmosphere, and good views can be obtained of brilliant objects such as the Moon or Venus, though anything in the nature of real fog is naturally hopeless. Conversely, very brilliant starlight nights often prove to be of no use, with images flickering about and every evidence of marked turbulence in the upper air.

In addition to a good telescope, it is essential to have good

eyepieces. Using a good instrument with a poor eyepiece is like using a good gramophone with a blunt needle; and this important fact is often overlooked.

Eyepieces are of different kinds, and will give different magnifications. Fortunately, they are so made that any eyepiece will fit any telescope; buying a new instrument does not involve buying a new set of eyepieces. For a 3-inch refractor, it is advisable to have several eyepieces, one giving low magnification (30 to 40 diameters) for general views, another (80 to 100) for normal drawing of planetary details, another (120 to 150) for use on good nights, and yet another (about 200) for use under conditions of exceptionally good seeing. However, it is a grave mistake to try to use too high a power. A smallish, sharp image will reveal more detail than a larger but diffuse one, and the slightest blurring of a planetary disk should be the signal to change to a lower magnification.

For my own 3-inch refractor, I have found that powers of about 100 are best for lunar and planetary work; 150 can sometimes be used to advantage, and I have used powers of over 200 to finish off almost completed sketches of the Moon, Mars, Jupiter and Saturn, though conditions have to be very steady. (The brilliant Venus will seldom allow use of more than 100, even against a light background.) With larger instruments, one can of course use increased magnifications. K. W. Abineri, one of Britain's leading lunar observers, does nearly all his work with a power of 240 on his 8-inch reflector, and this power is also suitable for the planets (apart from Venus, which is always troublesome). My own 12½-inch reflector will generally bear 350 on most planets, and Dr. Wilkins usually employs between 300 and 400 on his 15¼-inch reflector.

Experience with giant telescopes (mainly the Meudon 33-inch refractor, also the 25-inch Newall refractor and Dr. Steavenson's 30-inch reflector at Cambridge) has shown me that sharpness and light-collection are far more important, in the long run, than pure magnification. Powers of about 300 at Meudon showed far more detail than could be seen with greater magnifications on smaller telescopes. The golden rule should be: Use the highest power which will give a really clear, sharp, steady image. Do not tolerate the slightest blurring. If even a lower power will

not give good results, there is obviously something wrong with the atmospheric conditions, and the only answer is to give up observing until things improve.

Above all – never place any reliance upon a drawing made hastily or under poor conditions. Such work is not only useless, but actually misleading. One good observation is worth a thousand fairly good ones.

APPENDIX II

Astronomical Societies

It is advisable for our interested amateur to join an astronomical society. The advantages gained are manifold. He will not only receive the latest information, and be put in touch with other observers, but he will receive help and advice if he wants it.

The leading amateur society on this side of the Atlantic is the British Astronomical Association, founded in 1890 and now comprising over 2,000 members spread throughout the world. In addition to the amateurs, it includes a great number of professionals (the Astronomer Royal is a Past President). Observational sections are guided by experienced directors, and at the moment the directors of the planetary sections are: Mercury and Venus, H. McEwen; Mars, P. M. Ryves; Jupiter, Dr. A. F. O'D. Alexander (assisted by E. A. Whitaker and W. E. Fox); Saturn, M. B. B. Heath; the Moon, Dr. H. P. Wilkins (assisted by myself as Secretary and F. H. Thornton as editor of the Lunar Section periodical). These Sections issue memoirs from time to time, and also publish their results in the Association's monthly Journal; the Lunar Section also issues its own periodical. The B.A.A. also includes an Instruments and Observing Methods Section, directed by Dr. W. H. Steavenson, which deals with matters such as telescope construction and mounting.

The nearest American equivalent of the B.A.A. is the Association of Lunar and Planetary Observers, directed by Professor W. H. Haas, with its headquarters at Las Cruces, New Mexico. Its periodical, the *Strolling Astronomer*, is a mine of information, and here again there are specific Sections directed by experienced recorders: Mercury, J. T. Carle; Venus, Dr. J. C. Bartlett; Jupiter, C. Brooks; Saturn, T. L. Cragg; Mars and the Moon, Professor W. H. Haas.

The Astronomical Society of the Pacific, with its headquarters in San Francisco, is an eminent association including some of America's foremost astronomers. The bi-monthly Publications

contain information of extreme value upon all branches of astronomy, while the mainly non-technical monthly Leaflets will be of particular interest to the amateur.

No specific technical qualifications are needed for membership of these societies; the main requirements are enthusiasm and patience. A more recently-founded association, formed mainly to help school-age beginners, is the Junior Astronomical Society (London); secretary, E. W. Turner. Patron of this Society is Dr. J. G. Porter.

APPENDIX III

Useful Work for the Amateur

(1) *Mercury*

It must be admitted that little useful work can be done without large telescopes, but it is always a source of satisfaction to catch sight of the tiny, pinkish planet in the morning or evening twilight, and to watch its phases. Occasionally, definite markings can be made out; I have seen the Solitudo Criophori with my 3-inch. The main trouble about observing Mercury is that unless it can be located in broad daylight, which is virtually impossible unless the telescope is equipped with setting circles and clock, it has to be observed when low in the sky, so that its light is shining through the full thickness of our atmosphere and the definition suffers.

(2) *Venus*

Despite the general paucity of detail, Venus is an interesting object in a small telescope. The main points to be looked for are as follows:

(*a*) Phase. It is desirable to note the exact time of dichotomy, as, as is explained in Chapter IV, the predicted date is frequently wrong.

(*b*) The shadings, which should be drawn as definitely as possible.

(*c*) The brighter areas, including the persistent cusp-caps with their dark bordering collars.

(*d*) Irregularities in the terminator.

(*e*) Any sign of the Ashen Light.

Venus, however, is an extremely difficult object to observe. The dazzling brightness makes estimations of colour unreliable, and one must be wary of terrestrial atmospheric effects; for instance, the oft-recorded serrated edge of the planet's terminator is due to this cause. It is seldom that a high magnification can be used, even when Venus is found in full daylight.

Venus appears much larger when in the crescent stage than when dichotomized or gibbous, as it is nearer, but generally speaking it is best to make all drawings the same size. A diameter of $1\frac{1}{2}$ inches to the full circle is quite convenient.

(3) *The Moon*

There is so much to see on the Moon, and so much work open to even the modestly-equipped observer, that it is impossible to give an adequate summary in a few paragraphs. (Further details will be found in my *Guide to the Moon.*) However, a few hints can be given.

First, one must learn to find one's way about the lunar surface. My own methods was to take an observing book and allot one page to each formation named in Elger's outline map. Within two years, I had secured at least two drawings of each formation – rough in many cases, but enough to enable recognition. The time and trouble taken proved well worth while in the end.

Ordinarily, a lunar feature is best seen when near the terminator, as the heights are then revealed by their shadows. A great crater such as Ptolemæus becomes very obscure when seen under a high light.

To begin a lunar sketch, first select the formation to be drawn, and survey it carefully. Then draw in the main outline, putting in shadows and coarser details. Next change to a higher power, and insert smaller details, afterwards checking everything to make sure there is no chance of error.

'Finished' shaded drawings, such as that of Tycho by L. F. Ball, are made by those who possess artistic skill; those who do not, such as myself, are better advised to keep to pen-and-ink 'line drawings', which can be made just as accurate, though much less pleasing to the eye. If a rough sketch is made at the telescope and later transferred into the observing book, the final result should be checked again at the telescope the same evening, to make certain that there are no mistakes in interpretation.

Above all, do not use too small a scale. 20 miles to the inch is convenient. A drawing of a large area such as the complete Sea of Showers, drawn on a small scale, is quite useless. A large crater such as Plato should be drawn with a longest diameter of something like three inches.

A small refractor will show much detail near the lunar limb which has not yet found its way on to the charts, and there are many other fields of investigation, such as the mapping of the elusive rays which appear over the limb and seem to come from some crater on the Moon's hidden side. Moreover, there is always the chance of finding something unusual. Many textbooks still say that the Moon is a completely dead and changeless world, where nothing ever happens; but we know now that this view is not correct.

(4) *Mars*

Mars is rather a difficult object for a small aperture. It only comes to opposition every other year, and generally speaking it is only near enough to be well studied for a month or so on either side of opposition date. However, a small telescope will show considerable detail, and valuable work can be carried out with instruments of 5 or 6 inches aperture.

Owing to the smallness of the disk, Mars is the one planet on which a high power should be used whenever possible. It is best to select a definite scale for drawings (2 inches to the planet's diameter is favoured by the B.A.A. Mars Section), and the phase, which is often considerable, should never be neglected. This can be worked out beforehand from the B.A.A. Handbook, and the disk outline prepared accordingly.

Before starting to draw Mars, it is advisable to spend some time in surveying the planet, until the eye has become thoroughly adapted. When the drawing is begun, the polar cap and main dark areas should be sketched in as quickly as is compatible with accuracy, as Mars is rotating on its axis and there is a slow but perceptible drift of the markings from east to west. Minor detail can then be added at leisure; and when the drawing is complete, and you are sure that nothing has been missed, written notes should be added about colours, intensities, and any interesting features.

Do not expect to see too much. At first, you may be able to make out nothing except for a small, ochre disk and the white polar cap; but as your eye becomes practised, you will see more and more.

In 1956, Mars will come as close to us as is ever possible; and

although it will be rather low for northern observers, it will be a splendid object, outshining everything else in the sky apart from the Sun, the Moon and Venus. The disk will be large enough to show much detail even in small instruments, and this will be an excellent time to begin serious observations of the planet.

(5) *The Minor Planets*

Here, the main interest for the amateur lies in identifying the minor planets, and following their movements from night to night. One (Vesta) can sometimes be seen with the unaided eye, and a number more are within the range of binoculars and small telescopes. Their positions can be found from the B.A.A. Handbook in conjunction with a star atlas (Norton's is the best), and with a little practice they can be recognized quite easily.

(6) *Jupiter*

It is no exaggeration to say that most of our knowledge of Jupiter is due to amateur astronomers, particularly those of the B.A.A. Jupiter Section. The disk of the great planet abounds in detail, and a modest aperture enables really useful work to be done.

Disk drawings should be made as quickly as possible, as the rate of spin is rapid and the drift of the markings is very obvious. A drawing should be completed within 10 minutes at the most with regard to major details (minor ones can be filled in more slowly, without altering the general framework). The colours seen should then be noted, and also the relative intensities of the various zones, using the nomenclature given in Fig. 24.

A very important part of the Jupiter programme is the taking of 'transits'. A feature 'transits' when it passes across the central meridian, e.g. the line passing through the two poles and the centre of the apparent disk. The transit-times should be estimated to the nearest minute, and accurate timing is necessary. It may seem a difficult task to make the estimates with sufficient precision, but it becomes strangely easy with a little practice, and it is possible to take many transits in the course of an hour or so as the markings drift steadily from right to left across the yellowish Jovian disk.

These transits are important because they allow the longitude of the feature to be calculated, and hence enable rotation periods to be derived. It is easy to work out the longitude of the feature from the tables in the B.A.A. Handbook, which give the longitude of the central meridian for every hour; the only arithmetic involved is simple addition.

As the equatorial zone (System I) rotates more rapidly than the rest of the planet (System II), two sets of tables are necessary, and there must be no confusion as to which set is to be used. (Remember that System I is bounded by the northern part of the South Equatorial belt and the southern part of the North Equatorial.) It is also necessary to indicate the part of the belt in which the feature lies; for instance, NEB(s) indicates 'the southern part of the North Equatorial belt'. The usual abbreviations are: P = polar, T = temperate, E = equatorial, Z = zone, D = disturbance, pr = preceding (western), f = following (eastern).

A disk drawing of the view on 1951 August 30 is shown in Plate XXVIII and may be compared with the sketch of detail in the N.E.B. (Plate XI). It may also be useful to give an extract from my observation book on that particular night:

> 1951 *August* 30. Conditions good, 8½ in. Reflector, ×350. Much detail in N.E.B. and S.T.B. The N.T.B. shades away into a narrow bright zone, with the belt north of it (the N.N.T.B.) fairly broad. The N.P.Z is darker than the S.P.Z.; the equatorial zone turbulent and disturbed in the region of the main spot. No local colour. Drawing commenced 0h 25m, finished 0h. 34m.

Transits:

G.M.T.	*Feature*	*Longitude* *System I*	*Longitude* *System II*
0·34	Point midway between 2 condensations in STB.	—	165·7
0·34	Pr. hump enclosing white spot in NEBs.	110·4	—
0·37	Pr. end of broadening of the STB. ...	—	167·5
0·44	Centre of white spot, NEBs. ...	116·5	—
0·56	F. hump enclosing white spot, NEBs.	123·8	—
0·59	F. end of broadening of the STB. ...	—	180·8

G.M.T.	Feature	Longitude System I	Longitude System II
1·03	Pr. extension of hollow, NEBcentral ...	128·1	—
1·05	Inconspicuous broadening, SEB (Pr. end.)	129·3	—
1·07	Pr. part of whitish area, NEZ ...	130·5	—
1·12	Pr. part of whitish area, SSTZ ...	—	188·6
1·19	C. of hollow between spot and dark notch, NEB	137·8	—
1·21	C. of hollow, STB	—	194·0

At this period, Jupiter was not particularly active; but often 50 to 60 transits can be taken in a night. It is these observations which will eventually lead us to a real understanding of how the planet is built up.

Surface details on the Galilean satellites cannot be made out except with large instruments, but it is of interest to estimate their colours and brilliancies, particularly in the case of Callisto, while the colour of Io also needs careful checking. Unusual things are sometimes seen. For instance, I have observed Io brighten up for no apparent reason, gaining half a magnitude in the course of a few hours. Neither are colour observations of the Galilean moons in good accord, quite apart from the possible fading of the strong orange colour of Io.

The satellite phenomena – transits across the Jovian disk, shadow transits, occultations and eclipses – are always worth watching, not only because of their beauty but because of the chance of seeing something unusual; the double shadow seen by Bateson, described in Chapter 11, is an example. The times of all phenomena are predicted for each year in the B.A.A. Handbook, and also in the American periodical *Sky and Telescope*.

(7) *Saturn*

Saturn is in some ways a convenient planet. It bears high powers well, even better than Jupiter, and although there is not generally much surface detail there is activity at times, so that there is a chance of making a startling discovery – as Hay did on August 3, 1933, when he detected the famous white spot.

The paucity of well-defined detail means that transits are difficult to take, but when possible they should be observed in the same way as those on Jupiter. For this work, a telescope of at least 10 inches aperture is desirable. It is also of value to estimate the colours and intensities of the various zones of the planet, as marked and so far unexplained changes occur from time to time.

Cassini's Division is an easy object when the rings are fairly open, but the other divisions, even Encke's, are elusive, and should be carefully looked for; if seen, their exact positions should be noted, and preferably drawn. Attention should be paid to the Crêpe Ring, which is suspected of fluctuations in brilliancy; and it is worth searching for the oft-recorded but so far unconfirmed dusky ring outside Ring A. Estimate the colours and intensities of the rings, compared with each other and with the disk, and when a disk drawing is being made take great care to put in the shadows (rings on disk, disk on rings) accurately.

Like nearly all other celestial bodies, Saturn sets its own problems. The Cassini Division sometimes appears more conspicuous on one side of the globe than on the other, though it is difficult to explain why (foreshortening is not the cause); and when the rings are almost edge-on, they are sometimes of unequal brightness along their length. Deformations have been recorded, and Ball and Barker have even seen the globe apparently eccentrically placed with regard to the ring-system, indicating some unusual optical effect.

Occasionally, Saturn passes in front of a star; and this is an important event, as it enables the transparencies of the various rings to be gauged.

Any 3-inch refractor will show Titan, also Rhea and (at its western elongation) Iapetus. I have also picked up Tethys and Dione. A 6-inch will show Tethys and Dione well, and perhaps Enceladus, while I have caught Mimas with an 8½-inch reflector and Hyperion with my 12½-inch. Phœbe is more difficult. It is important to estimate the relative brilliancies of the satellites; Iapetus is particularly interesting in this respect.

(8) *Uranus*

The main task here, with a small telescope or even with binoculars, is to estimate the brightness of the planet, which – as has been pointed out in Chapter 13 – varies unaccountably.

The path of Uranus among the stars is given for each year in the B.A.A. Handbook, and the stars suitable for comparison are given together with their magnitudes. All that need be done is to identify Uranus in the star-field, and then check its brightness against a star whose brilliancy is known; with practice, the results can be made very accurate, and we should learn much from them. A systematic programme of this sort is being carried on by the members of the A.L.P.O.; but this was only started in 1951, and as the fluctuations of Uranus are very slow, no definite results have been obtained as yet.

(9) *Neptune*

Neptune can be found with a small telescope, but its surface details are of course beyond the range of any but the largest instruments. Its brilliancy may be estimated in the same way as that of Uranus, though Neptune's light appears to be comparatively steady.

(10) *Pluto*

Pluto can be glimpsed with a moderate telescope of 8 to 10 inches aperture, but it is difficult to identify, as it looks like a minute, yellowish star.

Lastly, it cannot be too strongly emphasized that each drawing should be accompanied by the following data: date, time (using the 24-hour clock, and never using Summer Time), name of observer, type and aperture of telescope, magnification, and meteorological conditions prevailing. If any of these facts are omitted, the drawing loses most or all of its value.

It will be seen from the above notes that the owner of even a modest telescope has a wide field of research open to him. No clear night, winter or summer, need be dull; the planets are always changing, and their moods, their caprices, their obstinate refusals to obey prediction make them fascinating companions.

APPENDIX IV

Planetary Literature

Much has been written about the planets, and any good general book on astronomy contains a great deal of useful information; also of extreme value are the publications of societies such as the B.A.A. and the A.L.P.O., as well as a few separate magazines such as *Sky and Telescope* in America and *The Observatory* in England. A more recently-founded English periodical which contains much of interest to the amateur planetary observer is *Vega*, with its editorial office in Chester.

The only book (or, rather, booklet) dealing entirely with Mercury is by E. M. Antoniadi, and is entitled *La Planète Mercure*. It was published by Gauthier-Villars (Paris) in 1934, and can still be obtained from the publishers. It is, of course, in French. It is based on a study of Mercury made by Antoniadi with the great 33-inch Meudon refractor.

Venus has yet to have an entire book devoted to it, but there are many which deal with Mars. Lowell's three volumes – *Mars*, *Mars as the Abode of Life*, and *Mars and its Canals*, published by Macmillan between 1895 and 1906, can still be obtained; Antoniadi's *La Planète Mars*, in French and based on his work at Meudon, was published by Hermann (Paris) in 1930, and is most detailed and comprehensive. More recently Dr. Gérard de Vaucouleurs, one of France's leading planetary observers, has written two books on the subject. My translation of the first, *The Planet Mars*, was published by Faber & Faber in 1949, and has run to several editions, the latest of which appeared in 1952. Dr. de Vaucouleurs' larger and more technical book, *Physics of the Planet Mars*, appeared in English in 1954. Being translated into English is a book on Mars by Tsuneo Saheki, the eminent Japanese observer; and Dr. Hubertus Strughold, a distinguished American biologist who is also an astronomer, has recently published a most valuable volume entitled *The Green and Red Planet*.

In 1882, R. A. Proctor wrote *Saturn and its System*, published

by Chatto and Windus. This is the only major work dealing with Saturn, and is still of value, though by this time it is naturally in need of extensive revision.

The Moon has its own literature, not listed here as the most important works are given in my own *Guide to the Moon*, first published by W. W. Norton (New York) and Eyre & Spottiswoode (London) in 1953.

APPENDIX V

Tables of the Planets

Planet	*Mean distance from the sun (miles)*	*Periodic time*	*Axial rotation*	*Orbital eccentr.*	*Orbital incl. (°)*	*Mean Orbital velocity (mi./sec.)*	*Equatorial diam. (miles)*	*Mass (Earth=1)*	*Volume (Earth=1)*	*Escape vel. (mi./sec.)*	*Surface grav. (Earth=1)*	*Density (water=1)*	*Max. surface temp. (°F.)*
Mercury	36,000,000	88 days	88 days	0·206	7·0	29·7	3,100	0·04	0·06	2·6	0·27	3·8	770
Venus	67,200,000	224 ”	30 days?	0·007	3·4	21·7	7,700	0·83	0·88	6·3	0·85	5·2	140?
Earth	93,009,000	365¼ ”	23 h. 56 m.	0·017	0	18·5	7,926	1	1	7	1	5·5	140
Mars	141,500,000	687 ”	24 h. 37 m.	0·093	1·9	15·0	4,200	0·11	0·15	3·1	0·38	4·0	85
Jupiter	483,300,000	11¾ years	9 h. 53 m.	0·048	1·3	8·1	88,700	318	1,312	37	2·64	1·3	−200
Saturn	886,100,000	29½ ”	10 h. 14 m.	0·056	2·5	6·0	75,100	95	763	22	1·17	0·7	−240
Uranus	1,783,000,000	84 ”	10 h. 45 m.	0·047	0·8	4·2	32,000	15	64	13	0·92	1·3	−310
Neptune	2,793,000,000	164¾ ”	15 h. 48 m.	0·009	1·8	3·4	27,600	17	42	16	1·40	2·2	−360
Pluto	3,666,000,000	248 ”	?	0·248	17	3·0	3,600?	?	?	?	?	?	−400

Satellite	Discoverer	Mean dist. from primary (miles) (reckoned from centre of primary)	Period	Orb. eccentric. (to orbit of primary) (°)	Incl.	Diam.	Mag.
EARTH:							
Moon	—	238,000	27 d. 7 h. 43 m.	0·055	5° 9′	2,160	−12·5
MARS:							
Phobos	Hall, 1877	5,800	7 h. 39 m.	0·017	2·3	10	10
Deimos	Hall, 1877	14,600	1 d. 6 h. 18 m.	0·003	2·3	5	11
JUPITER:							
Amalthea	Barnard, 1892	113,000	11 h. 57 m.	Small	3°	150	13
Io	Galileo, 1610	262,000	1 d. 18 h. 28 m.	,,	3	2,310	5·5
Europa	Galileo, 1610	417,000	3 d. 13 h. 14 m.	,,	3	1,950	5·7
Ganymede ..	Galileo, 1610	666,000	7 d. 3 h. 43 m.	,,	3	3,200	5·1
Callisto	Galileo, 1610	1,170,000	16 d. 16 h. 32 m.	,,	2¾	3,220	6·3
VI	Perrine, 1904	7,120,000	250 d. 16 h.	0·155	28¾	100	13·7
VII	Perrine, 1905	7,290,000	259 d. 16 h.	0·207	28	35	17·0
X	Nicholson, 1938	7,300,000	260 d. 12 h.	0·140	28½	15	18·8
XII	Nicholson, 1951	13,000,000	625 d.	0·200	160	14	18·9
XI	Nicholson, 1938	14,000,000	700 d.	0·207	163	19	18·4
VIII..	Melotte, 1908	14,600,000	739 d.	0·380	148	35	16·0
IX	Nicholson, 1914	14,700,000	758 d.	0·248	156	17	18·6

Satellite	Discoverer	Mean dist. from primary (miles) (reckoned from centre of primary)	Period	Orb. eccentric. (to orbit of primary) (°)	Incl.	Diam.	Mag.
SATURN:							
Mimas	Herschel, 1789	113,000	22 h. 37 m.	0·019	26¾	300	12
Enceladus ..	Herschel, 1789	149,000	1 d. 8 h. 53 m.	0·005	26¾	400	11
Tethys	Cassini, 1684	183,000	1 d. 21 h. 18 m.	Very small	26¾	800	10½
Dione	Cassini, 1684	235,000	2 d. 17 h. 41 m.	0·002	26¾	1,000	10½
Rhea	Cassini, 1672	328,000	4 d. 12 h. 25 m.	Very small	26¾	1,100	9¾
Titan	Huygens, 1655	760,000	15 d. 22 h. 41 m.	0·029	26	3,500	8
Hyperion ..	Bond, 1848	920,000	21 d. 6 h. 38 m.	0·119	26	200	13
Iapetus	Cassini, 1671	2,220,000	79 d. 7 h. 56 m.	0·029	16¼	2,000?	8¾
Phœbe	Pickering, 1898	8,050,000	550 d. 10 h. 50 m.	0·166	174	150	14
URANUS:							
Miranda	Kuiper, 1948	76,000	1 d. 9 h. 50 m.	Small	98	200	17
Ariel	Lassell, 1851	119,000	2 d. 12 h. 29 m.	,,	98	1,500?	14
Umbriel	Lassell, 1851	166,000	4 d. 3 h. 28 m.	,,	98	800?	14¾
Titania	Herschel, 1787	272,000	8 d. 16 h. 56 m.	,,	98	1,500?	14
Oberon	Herschel, 1787	364,000	13 d. 11 h. 7 m.	,,	98	1,500?	14
NEPTUNE:							
Triton	Lassell, 1846	220,000	5 d. 21 h. 3 m.	Small	139	3,300?	13
Nereid	Kuiper, 1949	3,500,000	359 d.	0·760	Small	200?	19½

(The magnitudes and diameters of the satellites of Uranus and Neptune are most uncertain. The diameters of the satellites of Saturn are also uncertain.)

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